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Research Report 161

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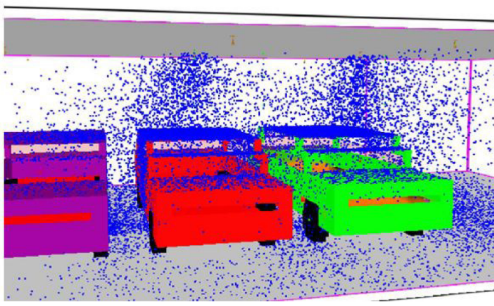

TAMPEREEN TEKNILLINEN YLIOPISTO
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Contents

Abstract

The goal of this study is to present background both for car fires and sprinklers design, focus being in sprinklers, because Eurocode method has not been yet accepted in all European countries, including Finland. The car-fires were not yet included in Eurocodes, although their calculation data has been widely accepted and validated with numerous tests completed in many fire laboratories in Europe and overseas.

The effect of sprinklers to the design value of the fire load [MJ/m^2] is taken into account in EN 1991-1-2 Annex E using factors considering different active firefighting measures. Two factors deals with sprinklers and take into account: automatic water extinguishing system (0.61) and independent water supplies (0 => 1.0, 1 => 0.87, 2 => 0.7). In this report the Eurocode method is studied for car fires numerically by modeling the fires with the program FDS Version 5.5.3 of NIST. Firstly, the computer model is validated against tests completed in UK 2006 - 2009. Tests included car fires without and with sprinklers. Secondly, the case studies of three medium size car fires are modeled without and with sprinklers recommended to car-parks.

In the case studies the environment is modeled aiming to extreme conditions in car-parks when considering the structural design in fire. This means that the design space is without walls to ensure enough available oxygen and the height of the space is small, 3 m. Temperatures near the ceiling are reported in all cases. Temperatures are calculated reducing the cars' heat release rates per area [kW/m^2] without sprinklers corresponding to reductions of the design fire loads with factors 0.61 x 1.0 = 0.61, 0.61 x 0.87 = 0.53 and 0.61 x 0.7 = 0.43. These temperatures are compared to the results which are calculated by modeling the sprinklers with car fires. Details of the numerical models are reported.
The Eurocode reduction does not take into account the fact that adjacent cars do not ignite, as is the case using the developed model and observed in the tests in the literature. The Eurocode reduction of fire load with sprinklers gives the same maximum temperatures as the simulation with sprinklers at the first peak of the heat release rate (HRR). The Eurocode method is reliable for design within this range, if the maximum temperatures in the beginning of the fire are those needed in fire design of structures. If it is used to simulate the temperatures after the first peak of HRR, then the temperatures are very conservative, based on the results.

Dr. Jukka Vaari from VTT, Finland, is acknowledged of the assistance for modeling sprinklers.

Introduction

Fire safety is one of the key issues when designing buildings. Car parks, open or enclosed, are typical in modern urban environment. Car fires have been studied since numerous years. The study of the heat release rate (HRR) of cars has begun only with car tests of VTT in Finland 1991 [Mangs & Loikkanen, 1991]. After that many researches have been completed and a wide summary of car fires is in [BRE, 2009]. Wide literature and interesting statistical data from New Zealand is given in [Li, 2004]. Not only cars, but also parts of cars, such as tires [Gratkowski, 2012] and engine compartments [Weisenpacher et al, 2010] have been studied. Proper heat release rate with respect to time from ignition is the main property when modeling fires, generally.

Modeling of car fires has been done in many cases using computational fluid dynamics (CFD) and most of the analyses, such as [Halada et al, 2012], have been completed using Fire Dynamics Simulator (FDS) by NIST [Mc Grattan et al, 2010, or older version]. Only CFD is considered in this study.

When considering the structural design of car parks the most simplified method is to use prescriptive rules appearing in many national standards. Fig. 1 illustrates fire resistance requirements in some European countries in 1993 for open car parks.

Figure 1. Fire resistance requirements in open car parks.

The goal of European technical and economic co-operation is that the safety level in Europe should be the same. Fig. 1 shows that it is not so, when using the prescriptive design. Moreover, the requirements of 30 - 90 minutes resistances with ISO 834 standard fire mean for steel structures expensive protections against fire. According to Fig. 1 this extra cost for structures is not needed e.g. in UK and in Germany. Anyway, most of designers use this method, because it is extremely easy to use, reducing the design costs of the building. Moreover, no standardized design methods are available for more sophisticated design.

When considering the structural design in fire the most advanced method is to use the probabilistic method where the effects (mechanical loads, fire) and the resistances including passive and active firefighting are determined with their statistic values (distribution, mean, variation) ending up to the required safety index appearing in the Eurocodes for accidental events for defined life time of the building. This method is used in [Schaumann et al, 2010] for open car parks. In that paper the requirement of Germany (R0, see Fig. 1) is also motivated. This method may be difficult to use by the average designers, although it is the most accurate.

The Eurocodes include possibility to use, not only fully probabilistic method, but also the performance based method which uses of relevant HRR data of the fire to determine the temperatures in fire. The Eurocode [EN 1991-1-2, 2003] includes also the reduction factors for fire loads when sprinklers are used. After determination of the gas and structure temperatures the resistances of structures can be checked during the entire fire. In most of the cases the heat transfer analysis and the mechanical analysis of structures can be done independently.

No design data for car fires are given in the Eurocodes. In [EN 1991-1-2, 2003, Annex E] are given reduction factors for fire loads with different active firefighting measures. Two factors deals with sprinklers and take into account: automatic water extinguishing system (0.61) and independent water supplies (0 => 1.0, 1 => 0.87, 2 => 0.7). In some countries, e.g. in Finland, these factors cannot be used in the fire design, as is stated in the National Annex of Finland. So, designers have no standardized basis to perform this kind of analysis for car fires, and further for car fires with sprinklers. One scope of this research is to give guidelines of the fire design for the car parks with respect to the fire loads, without or with sprinklers, and their modeling.

The main goal of this report is to give background data for the car fires and to study the usability of reduction factors for sprinklers appearing in the Eurocodes. It is believed by the authors, that the car fires generally are well studied and documented starting from typical cars in car parks of buildings (as in this study) ending up to the most worst situation in this context, petrol tankers, see [Haack et al, 2005]. The information dealing with subject is so large, that it could be implemented to future versions of the Eurocodes. In this report is given also background for the car fires with sprinklers. The vision is that the authorities in different countries could accept the Eurocodes for the basis of the performance based fire design with the context considered in this report. By these means the safety level and marketing of products in Europe will be more balanced in different countries. The summary of this report has been presented in ASFE conference, Prague 2013, to promote the same goal.

The outline of this report is as follows. Firstly, the car fire model for FDS version 5.5.3 is built including three adjacent cars. Three adjacent cars is one basic scenario when considering car fires. Four or more adjacent cars do not give any more information, as stated in [Schleich et al, 1997]. The developed model for the car fire is validated against one full scale fire test reported in [BRE, 2009]. Next, the same model is enlarged to include sprinklers. The model is validated against the full scale fire test with sprinklers reported in [BRE, 2009]. Validation criteria are to compare the gas temperatures around the cars during the fires. The calculated gas temperatures are compared to the measured gas temperatures in tests. Next step is to model a virtual open car park space of floor area 8 x 16 m^2 and free height of 3 m. The floor and the roof of the space are modeled as 100 mm thick concrete slabs. In this virtual car park are three cars and typical sprinklers, used in the car parks. The car fires are modeled without sprinklers and using different reduction factors for HRR curves. Finally, the temperatures got using the reduction factors of the Eurocodes are compared to the modeling results ending up to the conclusions.

Car fire model

Cars in car parks are categorized to the rank 1-5 based on a large European project [Schleich et al, 1997]. The characteristics of categories are given in Table 1.

Table 1. Mean car mass, mass lost and energy available to be released versus category.

category	car mass (kg)	mass loss (kg)	released energy (MJ)
1	850	200	6000
2	1000	250	7500
3	1250	320	9500
4	1400	400	12000
5	1400	400	12000

Examples of cars belonging to different categories are presented in Table 2.

Table 2. Examples of cars in categories.

trade-marks	category 1	category 2	category 3	category 4	category 5
Peugeot	106	306	406	605	806
Renault	Twingo-Clio	Mégane	Laguna	Safrane	Espace
Citroën	Saxo	ZX	Xantia	XM	Evasion
Ford	Fiesta	Escort	Mondeo	Scorpio	Galaxy
Opel	Corsa	Astra	Vectra	Omega	Frontera
Fiat	Punto	Bravo	Tempra	Croma	Ulysse
Wolkswagen	Polo	Golf	Passat	//	Sharan

In this report only car fires for cars in category 2 are considered because these are the most popular cars in Finland. The cars are located 600 mm from the adjacent cars. The fire starts at one car and the next car ignites 12 minutes after the previous [Joyeux et al, 2001] without sprinklers. In [Heinisuo et al, 2011] the car fire was modeled simply using a rectangular plane with burning top level. When using the same car model both without and with sprinklers, the model should be such that sprinklers do not affect directly to the fire inside the car, provided that cabriolets are not considered. So, some roofing is needed for the car model to prevent water inclusion into the car when sprinklers are activated. In this study inside each car is the plane 1.8 x 4.8 m^2 [Schleich, 2010] located at 500 mm above the floor level. The HRR curve is fitted to [Schleich et al, 1997] with peak value 8 MW at 25 minutes from ignition. The theoretical design curve of the burning plane is fitted so that the released energy for one car is 7500 MJ, as required by the categorization. Due to the other igniting objects, total released energy per one car in simulations was about 7650MJ (see Fig 3.). Fig. 2 illustrates HRR curves from different sources.

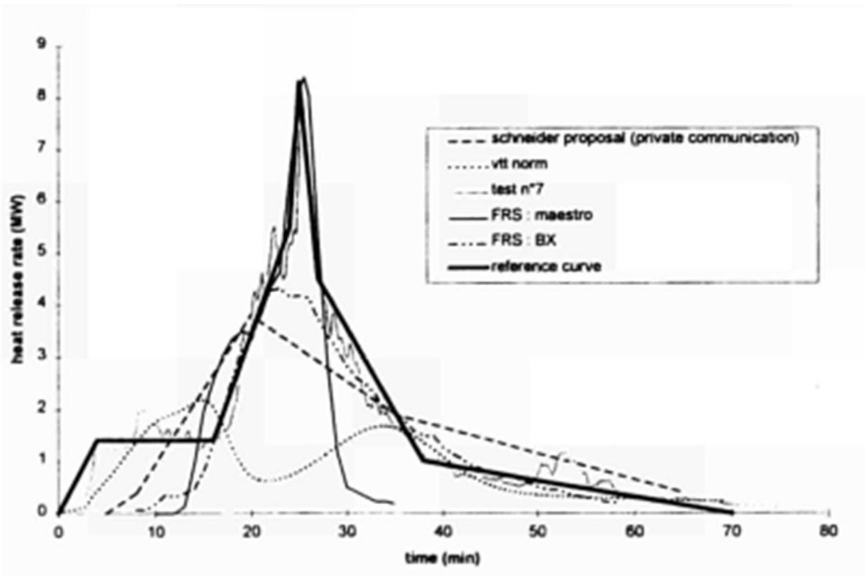


Figure 2. HRR curves for one car.

Figure 3 illustrates the HRR curve used in this study for one car. The simulations in this study are done for one hour (3600 s).

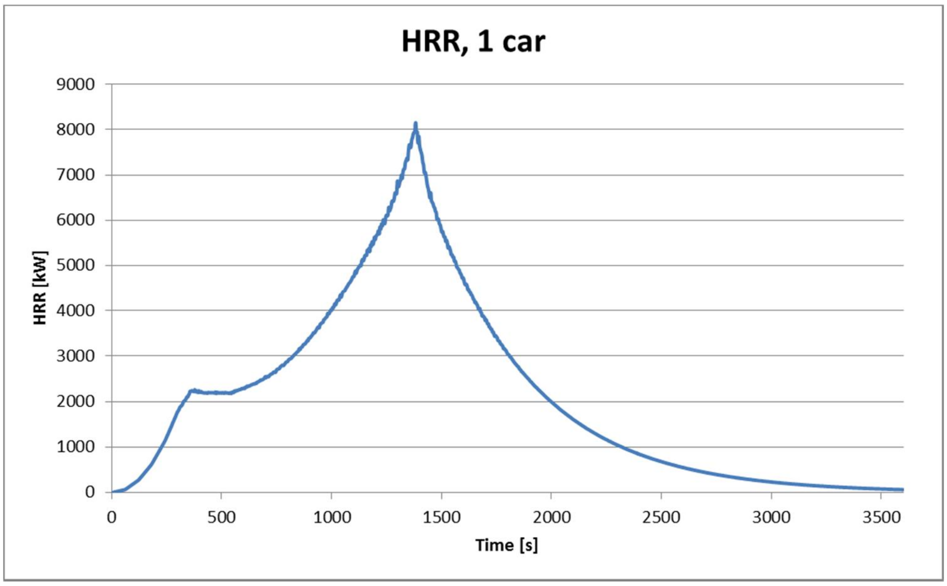


Figure 3. HRR curve used in this study for one category 2 car.

In order make it possible for fire to spread from one car to another, to the burning plane are given material properties describing inner parts of the car as given in Table 3.

Table 3. Properties of materials inside the car.

Object	”FABRIC”	"FOAM"	”POLYPROPYLENE”
Thickness [m]	0,002	0.1	0.1
Thermal conductivity [W/m*K]	0.1	0.05	0.16
Specific heat [kJ/(kg*K)]	1.0	1.0	1.9
Density [kg/m^3]	100	40	900
Reference	[Mc Grattan et al, 2010]	[Mc Grattan et al, 2010]	[Ineos, 2012]

Tires are objects which have independent HRR curve based on [Gratkowski, 2012]. Generally ignition temperature for tires is 371-425 ^{o}C [Gratkowski, 2012] but in this study the ignition temperature is set to 250 ^{o}C so that the total model of the car will work better with respect to the verification tests. The properties of the tires in the model are as presented in Table 4.

Table 4. Material properties of the tires.

Object	”NATURAL RUBBER”
Thickness [m]	0,01
Thermal conductivity [W/m*K]	0,13
Specific heat [kJ/(kg*K)]	1,88
Density [kg/m^3]	910
Reference	[Matbase, 2012a]

The experimental HRR curve [Gratkowski, 2012] for tires in vertical position is shown in Fig. 4 (blue curve).

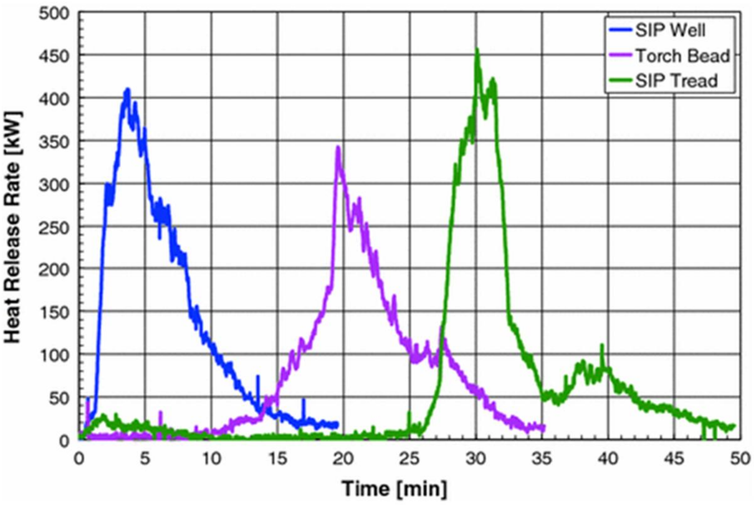


Figure 4. Experimental HRR curves for tires.

The HRR curve for tires used in this study is shown in Fig. 5.

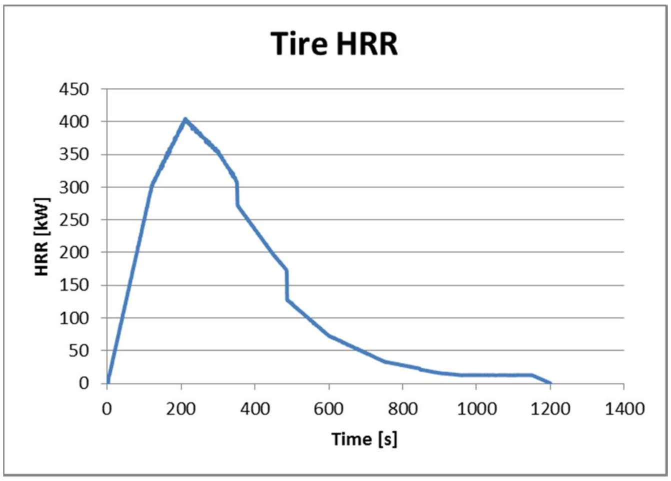


Figure 5. HRR curve for one tire.

The window breakage is supposed to happen at 300 ^{o}C [Weisenparcher et al, 2012]. The side windows are half open in the car which ignites first to get enough oxygen to enable the fire inside the car. The fire spreads via breaking windows and via burning tires from car to another so that second car ignites 720 s (12 minutes) after the ignition of the first car, and the third car ignites 1440 s (24 minutes) after the first. Two materials are used in windows. Automotive windows are usually made of laminated glass for windshields and tempered glass for sidelites and backlites [Saint-Gobain, 2012]. The properties of lites are given in Table 5.

Table 5. Properties of lites.

Object	”LAMINATED GLASS”	"TEMPERED GLASS"
Thickness [m]	0,004	0,006
Thermal conductivity [W/m*K]	0,2077	0,8
Specific heat [kJ/(kg*K)]	1,968	0,8
Density [kg/m^3]	2200	2500
Reference	[AIS, 2012]	[Saint-Gobain, 2012]

The car itself is modeled using non-burning wrought aluminum [Bertram & Buxmann, 2007], today used in cars. The properties of car structures are given in Table 6.

Table 6. Properties of car structures.

Object	”WROUGHT ALUMINIUM”
Thickness [m]	0,005
Thermal conductivity [W/m*K]	180
Specific heat [kJ/(kg*K)]	0,897
Density [kg/m^3]	2710
Reference	[Matbase, 2012b]

There are ventilation openings in front of the cars and around the tires. In two tires there are thermocouples to follow the spread of fire from car to another. At each burning plates there are also thermocouples to follow the ignition temperatures inside the car.

The grid size is 100 x 100 x 100 mm^3 near the car so the resolution [Heinisuo et al, 2008] is 25, which means rather dense and accurate grid. In some analysis is used grid size 200 x 200 x 200 mm^3 to accelerate the computations at the space 3 m from the edges of the computational space. Fig. 6 illustrates three adjacent cars in the model.

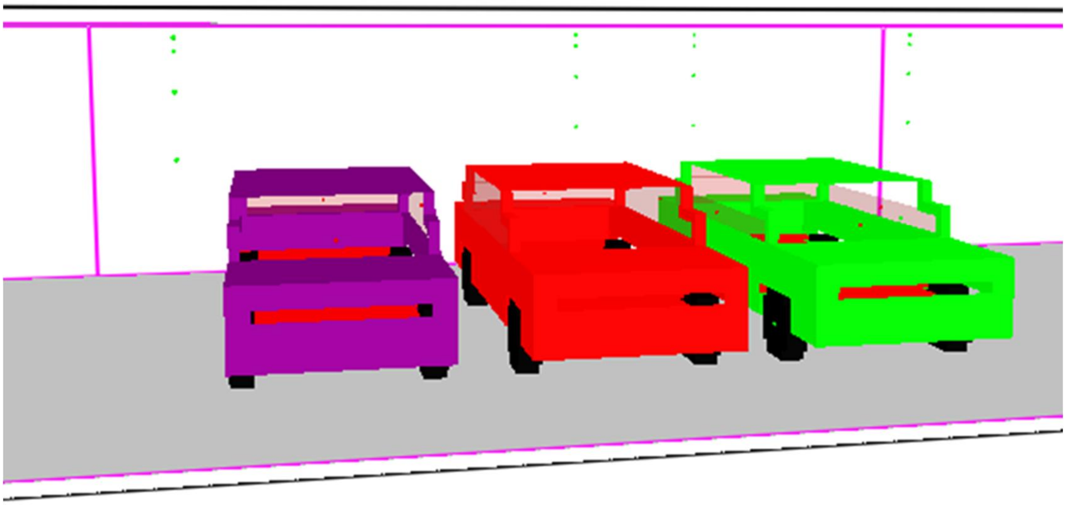


Figure 6. Tree adjacent cars in the model.

The HRR curve for three cars in Fig. 6 is shown in Fig. 7 when the fire starts at the green car and other cars ignite after 12 minutes (720 s) and 24 minutes (1440 s) after the first one. The curve is derived by summing up in time scale the curve shown in Fig. 3.

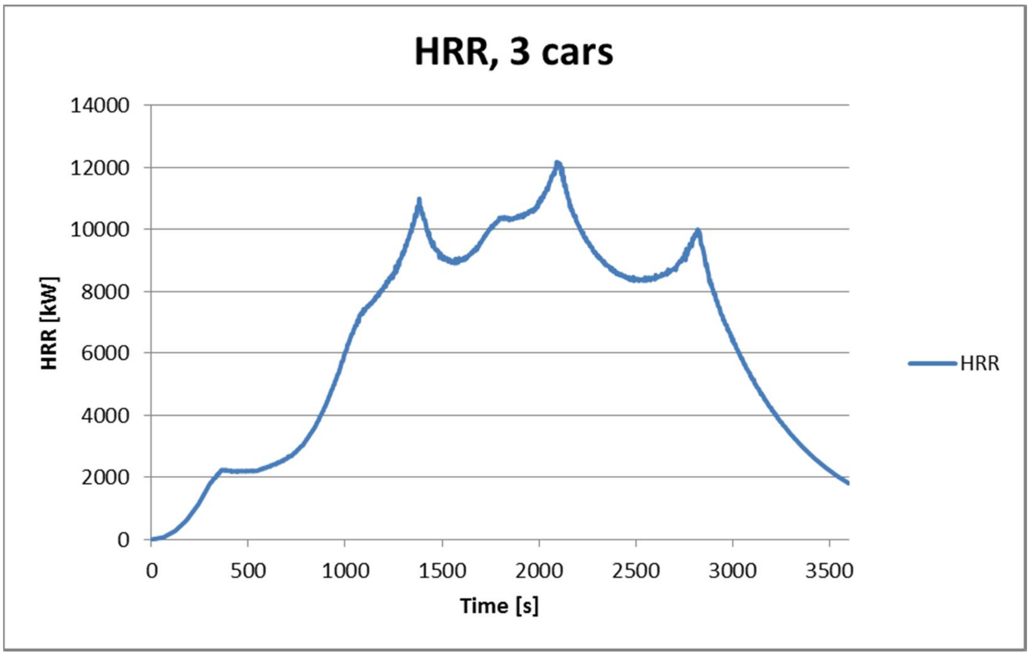


Figure 7. HRR curve for three adjacent category 2 cars.

No parallel computing facilities were used in the analysis.

Validation of the model against BRE test without sprinklers

The car fire model described above was fitted to the full scale tests of [BRE, 2009]. The size of the car in FDS model is 1.8 x 5 m^2. Other dimensions and properties are fixed to the experiments. The size of the building is 6 x 12 m^2 and the free height is 2.9 m. The test layout is shown in Fig. 8.

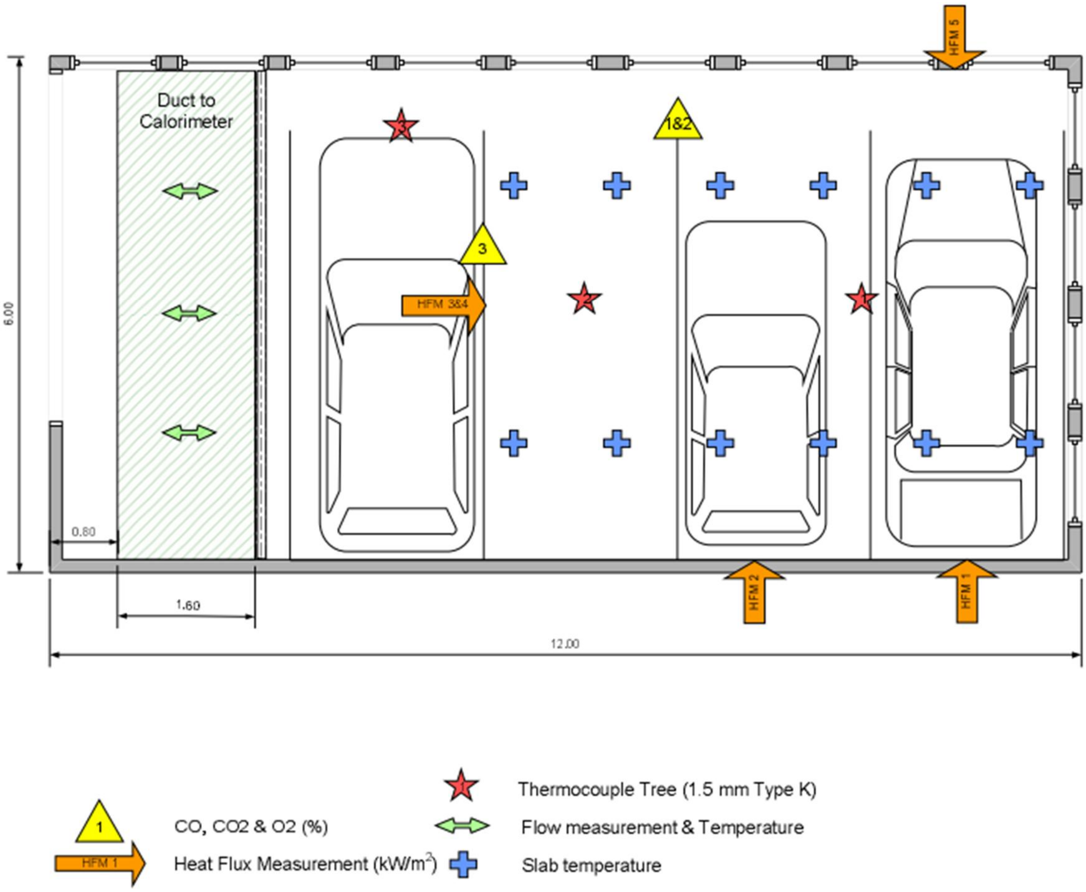


Figure 8. Test layout [BRE, 2009].

The properties of the floor, roof and the walls are given in Table 7.

Table 7. Properties of floor, roof and walls.

	Floor and roof	Walls
Material	Concrete	Breeze block
Thickness [m]	0.15	0.2
Thermal conduction [W/m*K]	1.37	0.15
Specific heat [kJ/(kg*K)]	0.88	0.84
Density [kg/m^3]	2400	1800
Reference	[SFPE, 2002]	[Breeze, 2012]

The properties of the thermocouples are given in Table 8.

Table 8. Properties of thermocouples.

Object	Type K 1.5 mm
Density [kg/m^3]	8667
Specific heat [kJ/(kg*K)]	0.46
Diameter [mm]	1.5
Reference	[Gilson, 2012]

Three thermocouple trees are located as in tests [BRE, 2009], see also Fig. 8. In each tree in the FDS model are five thermocouples located at 100, 200, 300, 500 and 1000 mm below the ceiling. In experimental tests there were more thermocouples in each tree, as seen later. The final FDS model is shown in Fig. 9.

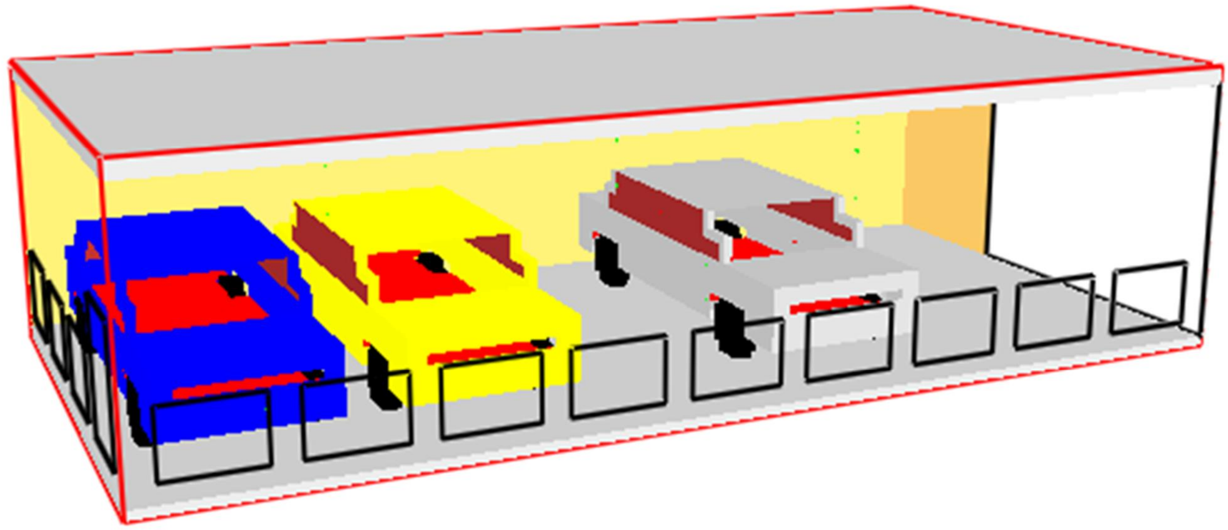


Figure 9. FDS model of tests.

The cars in tests were Renault Laguna (blue), Renault Clio (yellow) and Ford Mondeo Estate (Grey)-
The opening areas of the walls are:

- Short wall near blue car: 3.8 m^2;
- Long wall: 6.4 m^2;
- Short wall near grey car: 11.6 m^2;
- Total opening area is 21.8 m^2 which is 21 % of the wall area.

The grid size used in this analysis was 100 x 100 x 100 m^3 over the entire computational space, meaning 230400 cubes. The computer used in the analysis was: Intel® Core™ i5-2400 CPU @ 3.10GHz, RAM 4,00GB. The 30 minutes simulation without sprinklers took (total CPU) 22 hours for one run. With sprinklers the total CPU was 35 hours.

The HRR curves in the test [BRE, 2009] are shown in Fig. 10 when the blue car (car 1) ignites first.

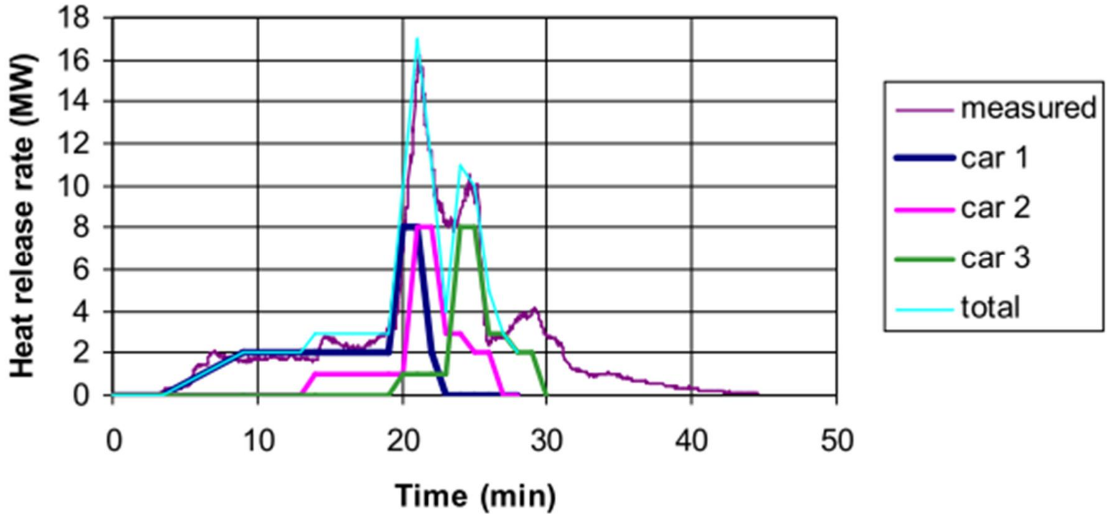


Figure 10. HRR curves in tests.

The HRR curve of the FDS model is shown in Fig. 11 when the ignition of the second car was set to 770 s and the third car to 1130 s (Model 1) as was in the tests.

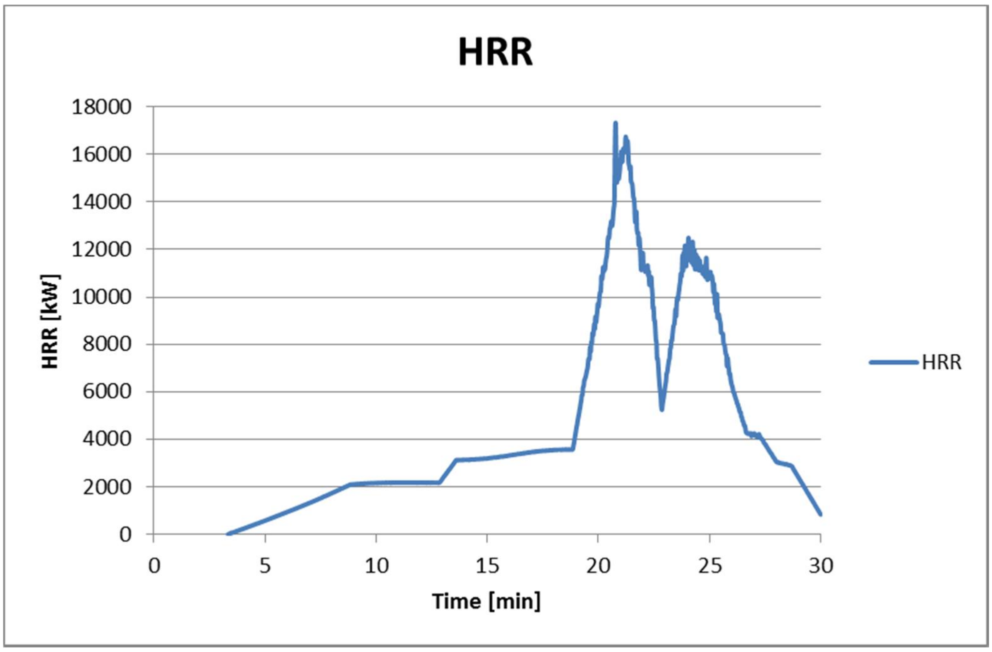


Figure 11. HRR curve when second and third car ignition was pre-set following tests.

Fig. 11 shows the HRR curve of the FDS model when the ignitions of the second and third car were based on material properties (Model 2) shown above for the parts of the car.

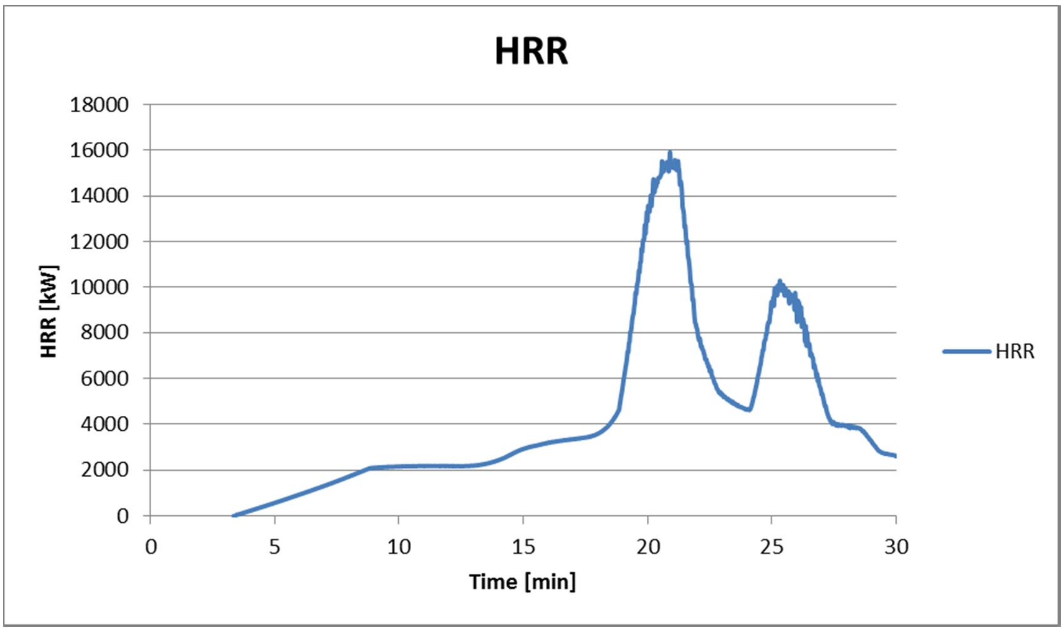


Figure 12. HRR curve when second and third car ignition was based on material properties.

The ignition times were 830 s for the second car and 1205 s for the third car. It can be seen that the FDS model describes well the tests with this respect (HRR). Fig. 13 shows the HRR curve, if the cars are modeled (Model 3) as planes 2 x 5 m^2.

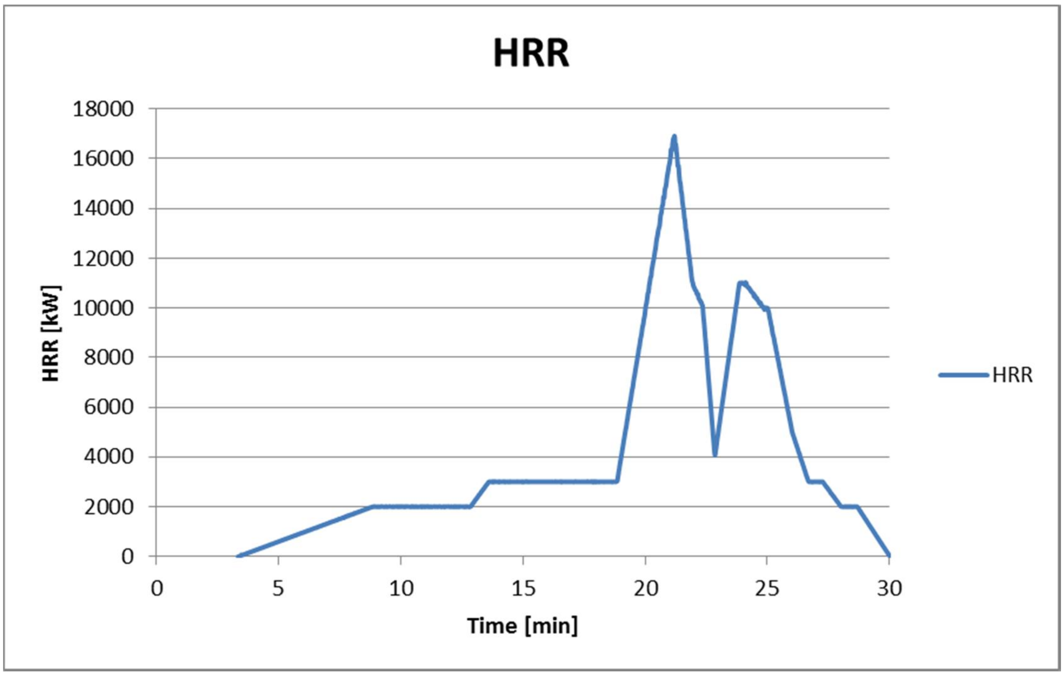


Figure 13. HRR curve when car fires are modeled as planes only.

The breaking of windows in Models 1 and 2 happened as shown in Table 9.

Table 9. Breaking of windows in Models 1 and 2 and test observations.

Blue car window breaking	Model 1, seconds	Model 2, seconds	Test observations
Right	Open	Open	
Left	385	384	
Front	465	466	
Back	453	453	
Yellow car window breaking			About 24 minutes
Right	618	616	
Left	862	937	
Front	990	1047	
Back	927	957	
Grey car window breaking			
Right	1243	1206	
Left	1273	1281	
Front	1336	1387	
Back	1304	1341	

The temperatures in three trees calculated with the FDS models 1-3 are shown in Figs. 14-22.

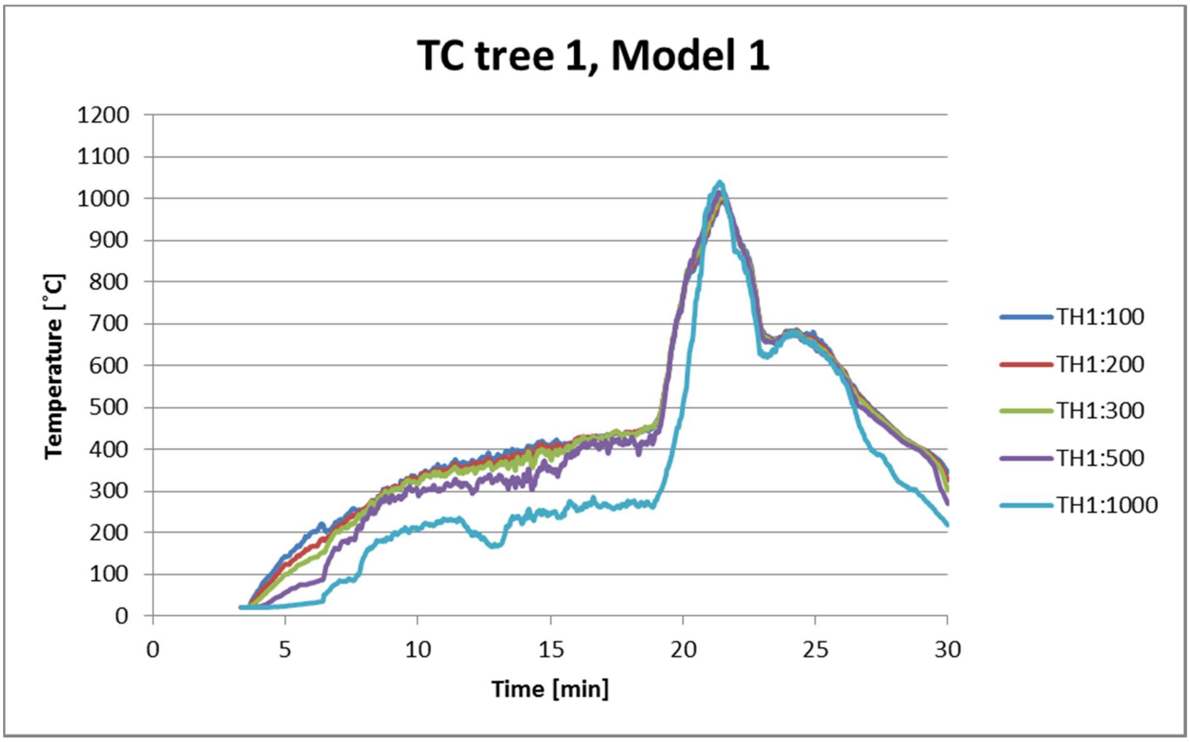


Figure 14. Temperatures in tree 1, Model 1.

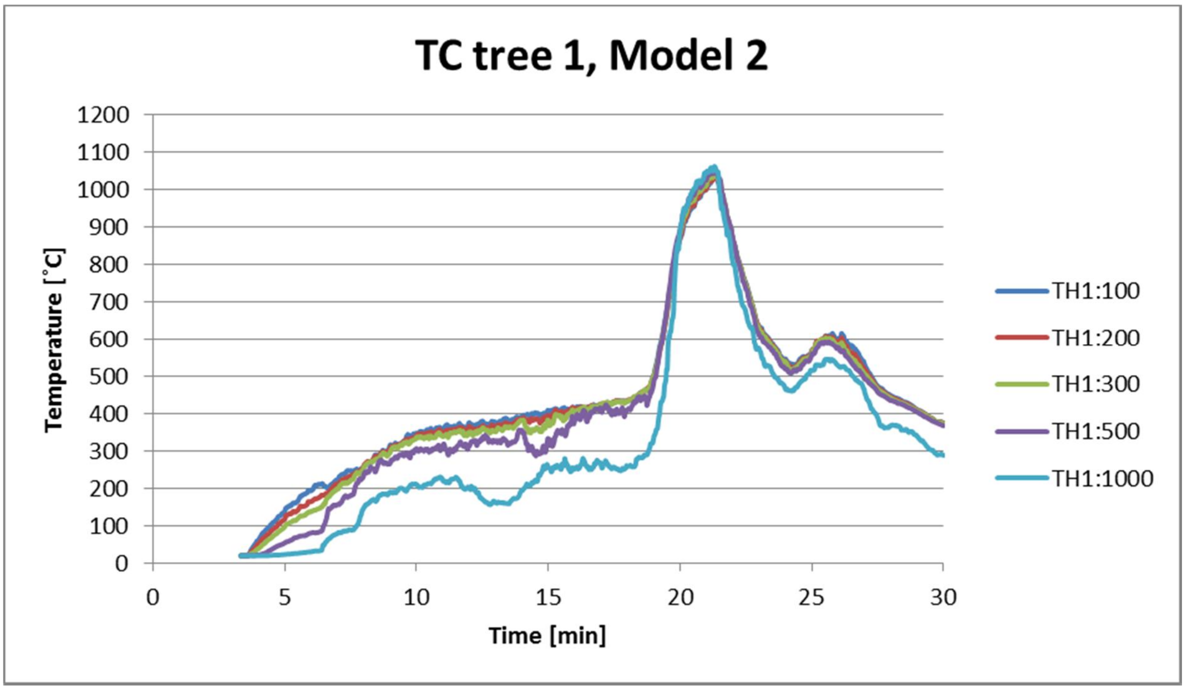


Figure 15. Temperatures in tree 1, Model 2.

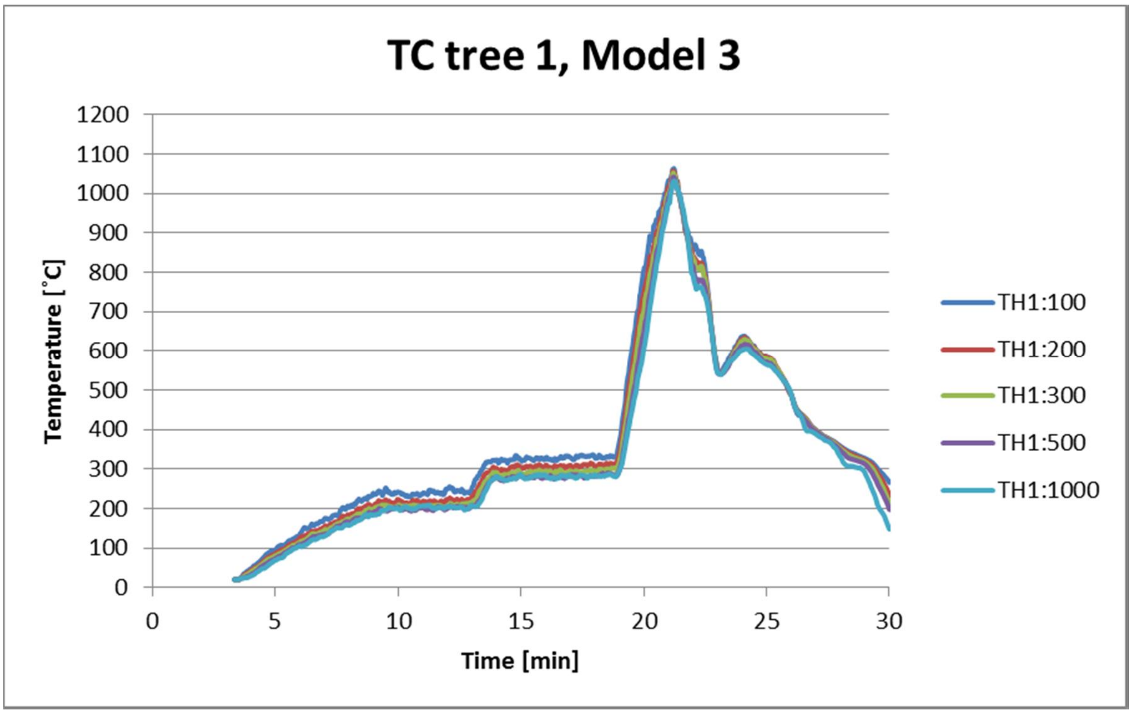


Figure 16. Temperatures in tree 1, Model 3.

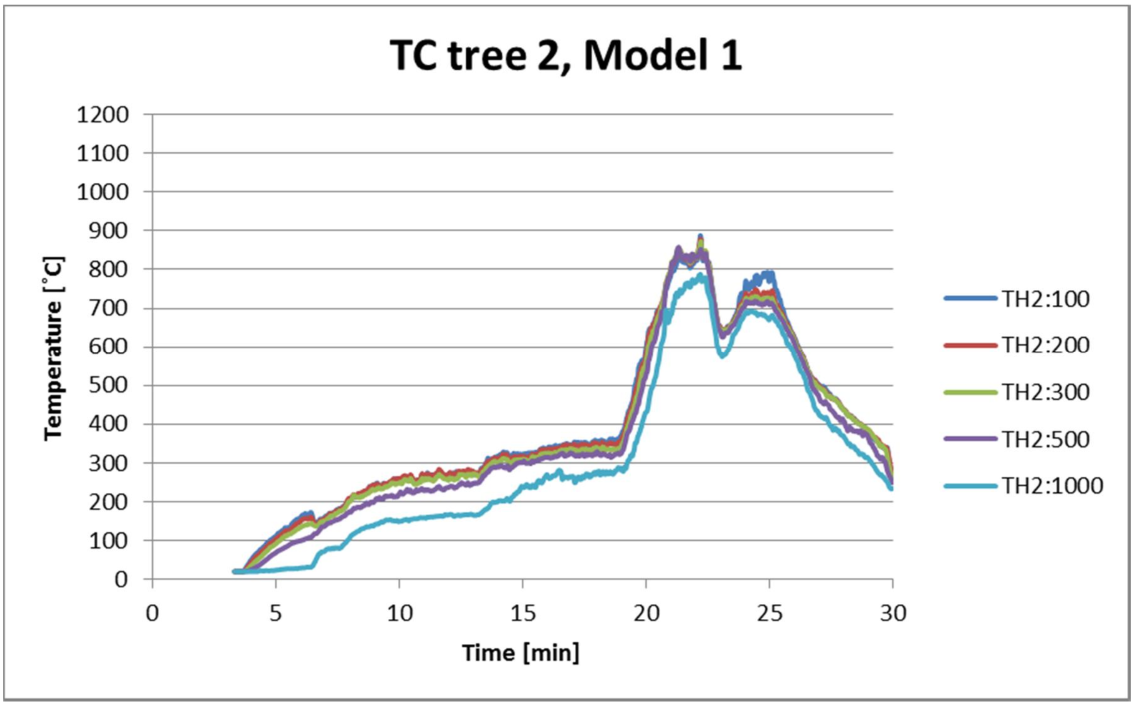


Figure 17. Temperatures in tree 2, Model 1.

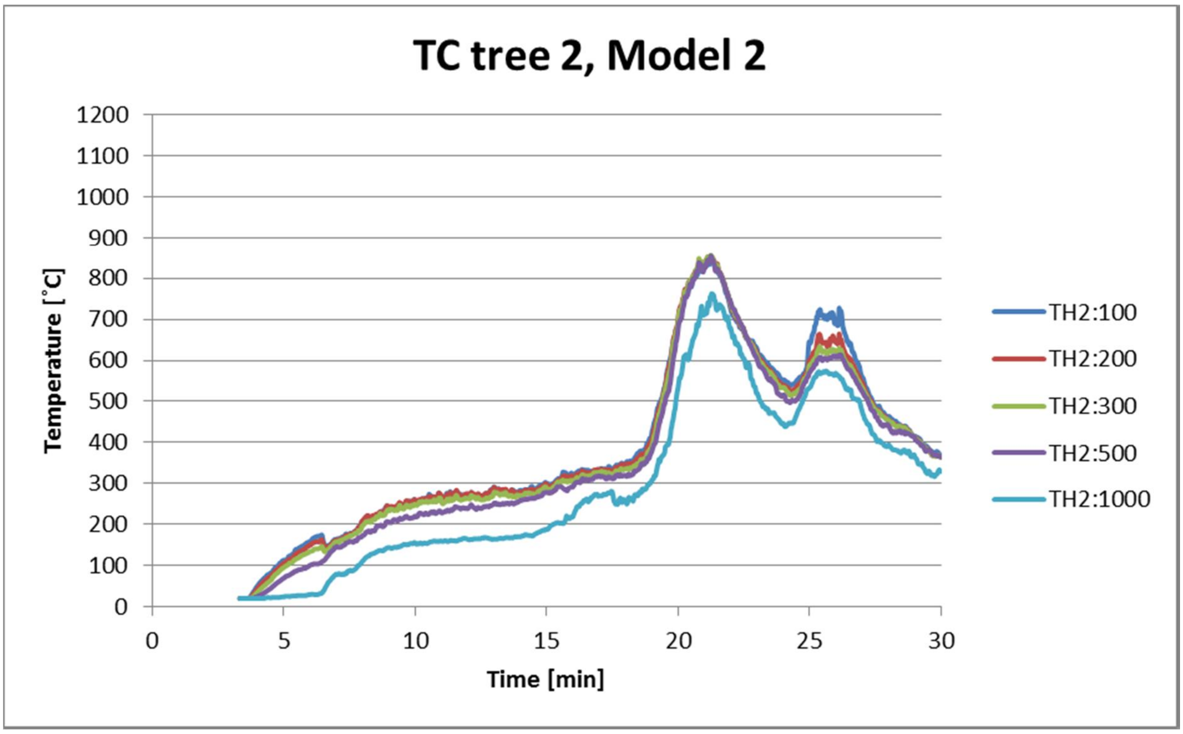


Figure 18. Temperatures in tree 2, Model 2.

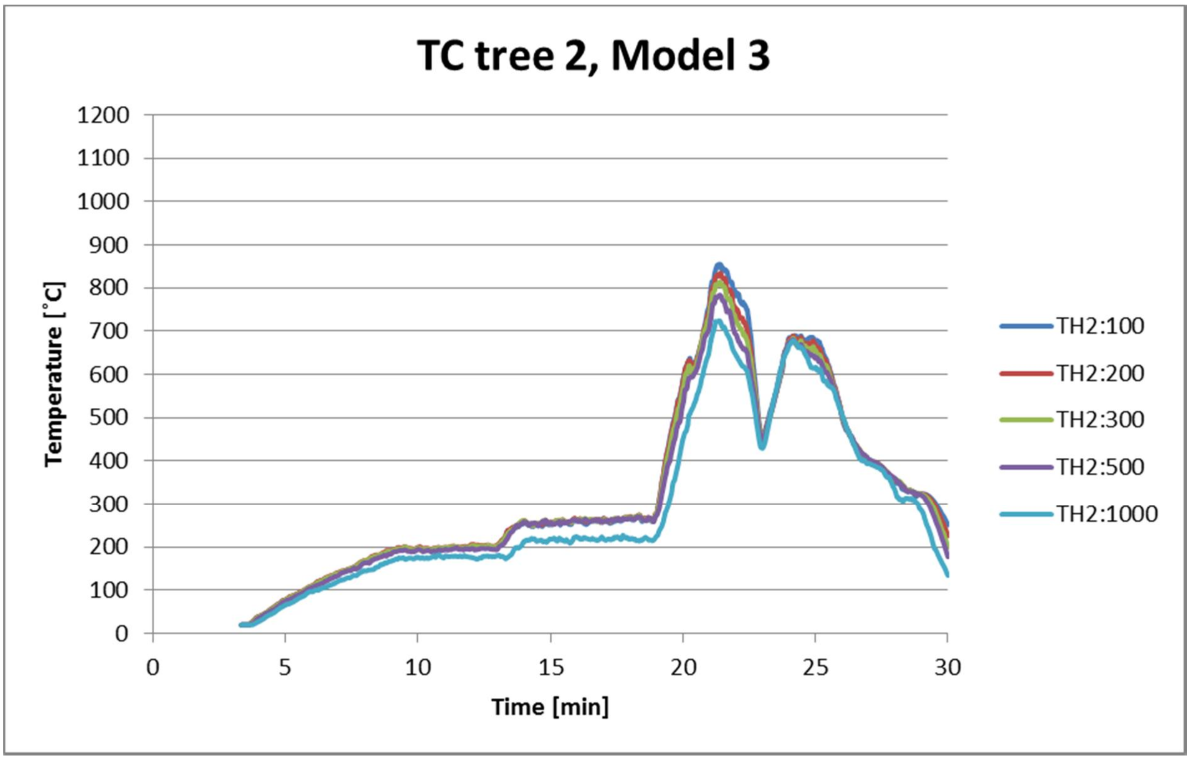


Figure 19. Temperatures in tree 2, Model 3.

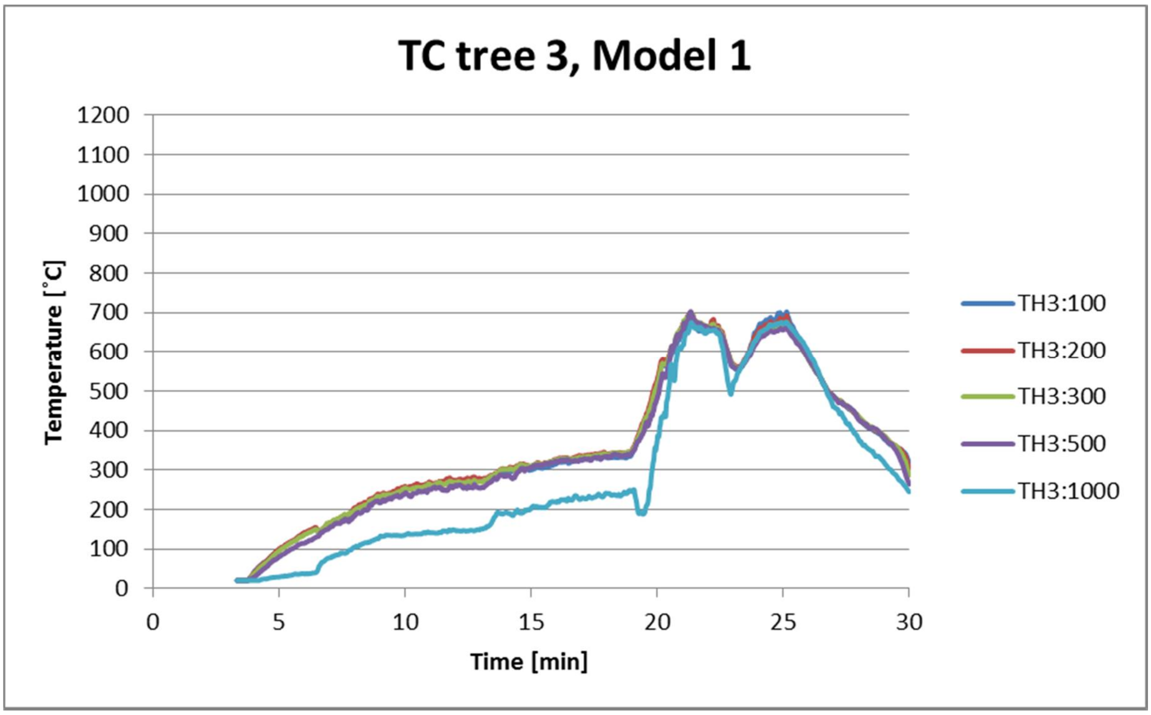


Figure 20. Temperatures in tree 3, Model 1.

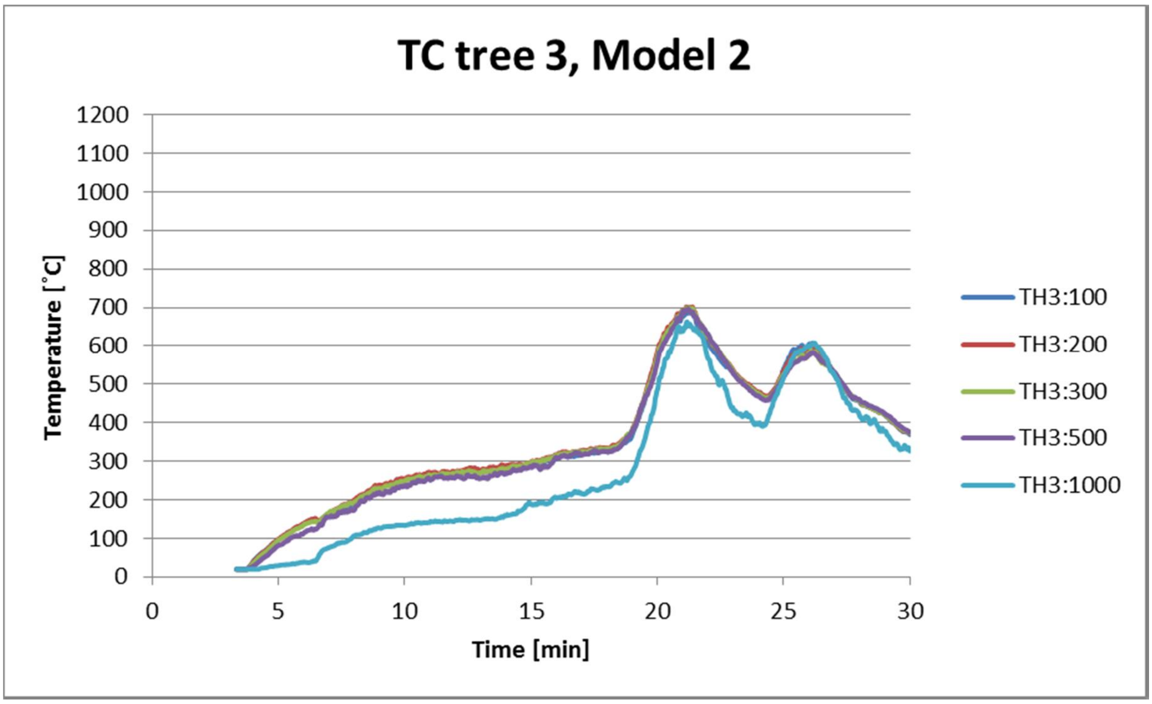


Figure 21. Temperatures in tree 3, Model 2.

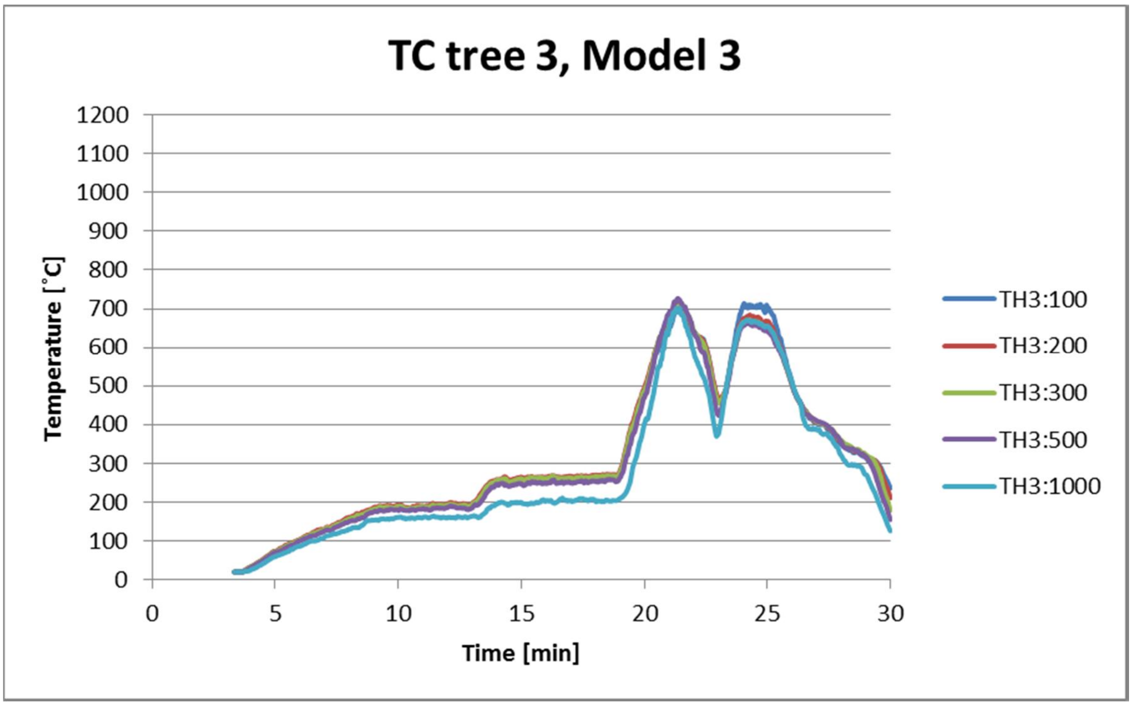


Figure 22. Temperatures in tree 3, Model 3.

In Figs. 23-25 are given the temperatures measured in the test.

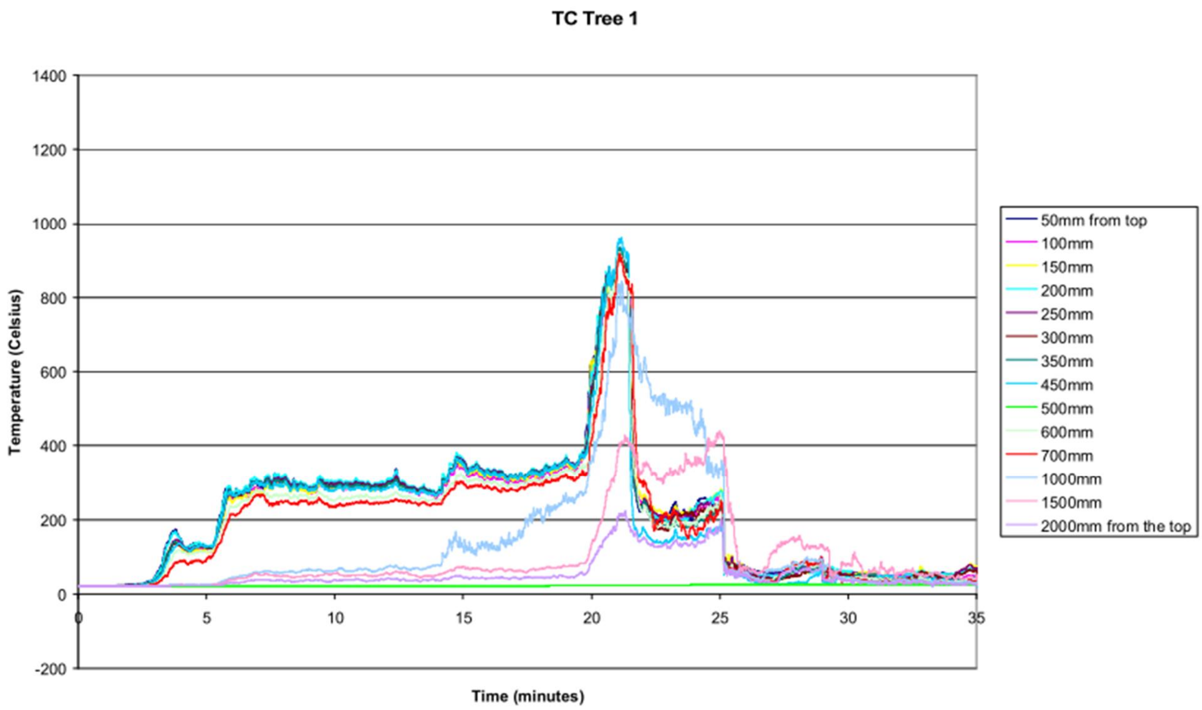


Figure 23. Temperatures in tree 1, Test.

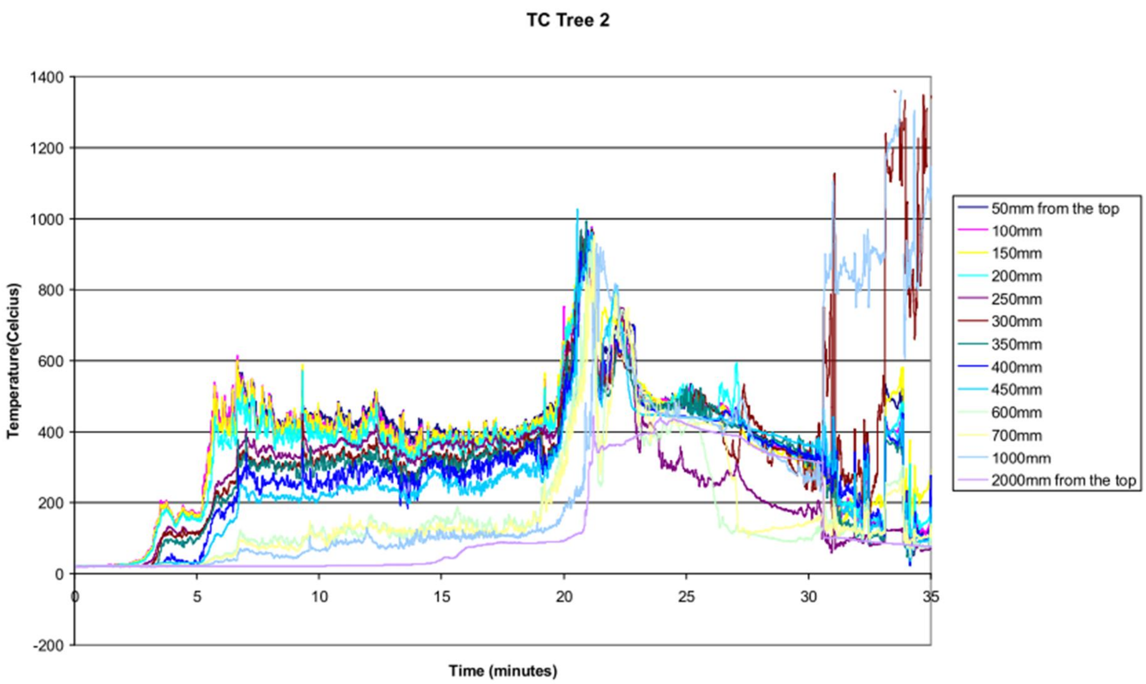


Figure 24. Temperatures in tree 2, Test.

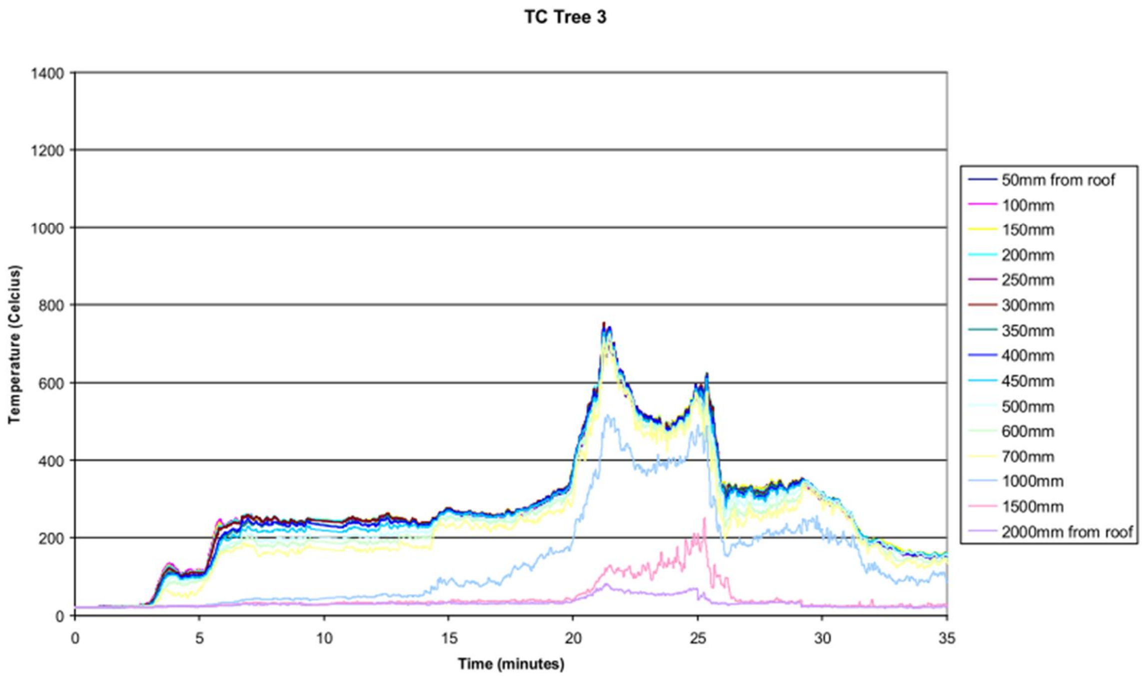
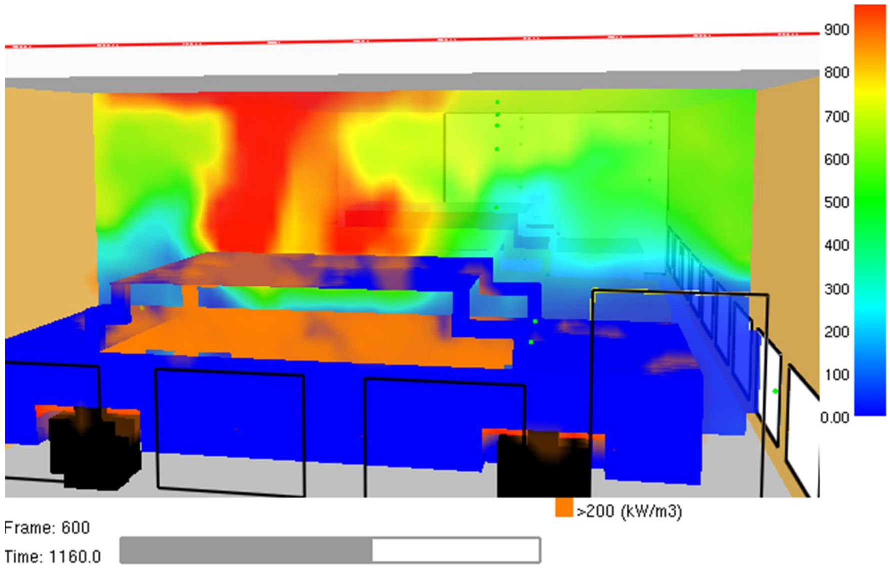
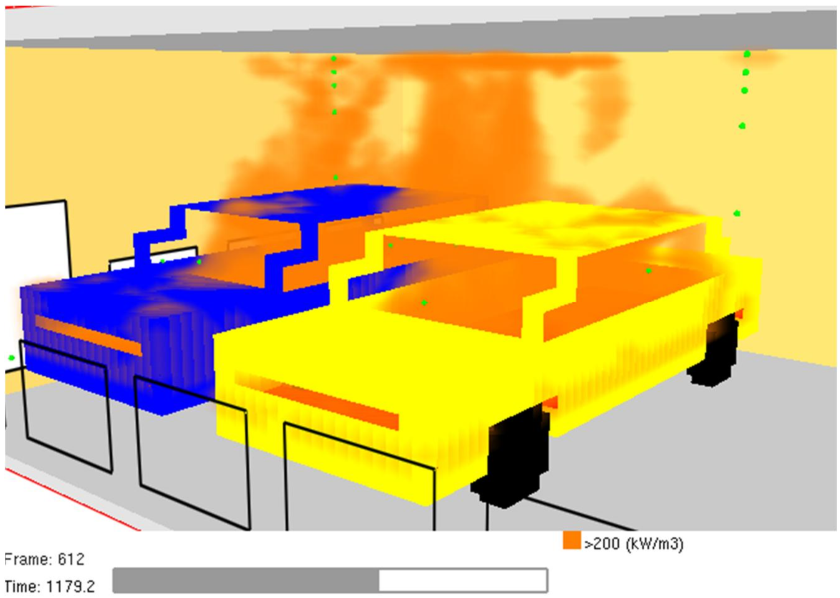


Figure 25. Temperatures in tree 3, Test.

It can be seen that all FDS models give about the same distribution of temperatures in trees. In tree 1 the maximum temperatures in FDS are about 1050 ^{o}C and in the test about 950 ^{o}C. In tree 2 the models give the maximum temperatures about 900 ^{o}C and in the test the maximum was about 1000 ^{o}C. In tree 3 the maximum temperatures both in the FDS results and in the test were about the same 700 ^{o}C. As a conclusion the FDS models simulate rather well the test without sprinklers.

In Fig. 26 are given snapshots of FDS's Smokewiev during the fire, see time bar in figures.


900
800
700
600
500
400
300
200
100
0.00
>200 (kW/m3)
Frame: 600
Time: 1160.0


>200 (kW/m3)
Frame: 612
Time: 1179.2

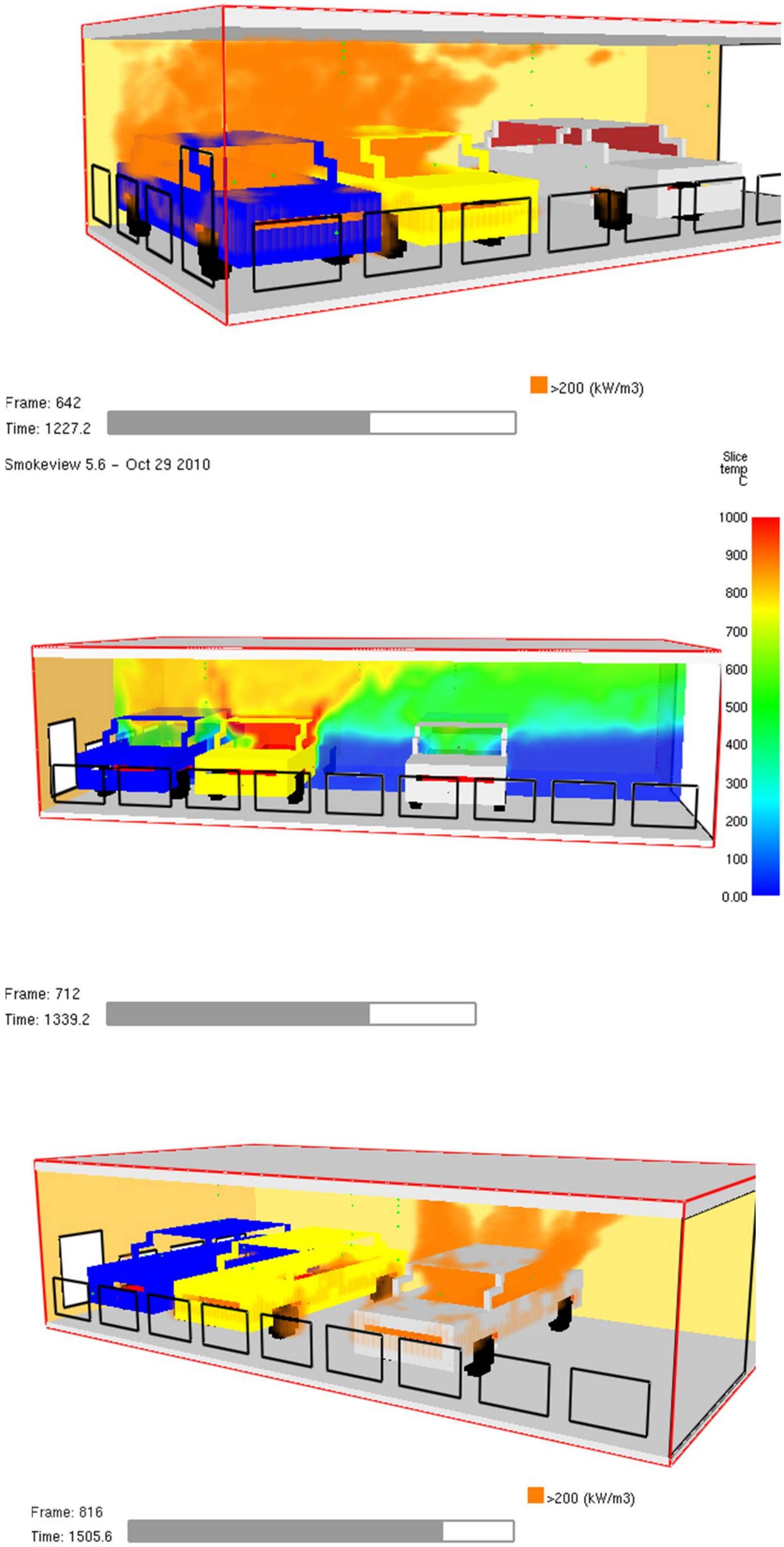


Figure 26. Snapshots of FDS simulation.

Figs. 27 and 28 show situations in the test.

Figure 27. 6 minutes after ignition.

Figure 28. 21 minutes after ignition.

Validation of the model against BRE test with sprinklers

The cars in the sprinkler test were Renault Grand Escape, Seat Ibiza and Land Rover Freelancer located as in the previous test. The sprinklers in the test were with OH2 classification, 5 mm/min and 12 m^2 per head. The layout of sprinklers is given in Fig. 29.

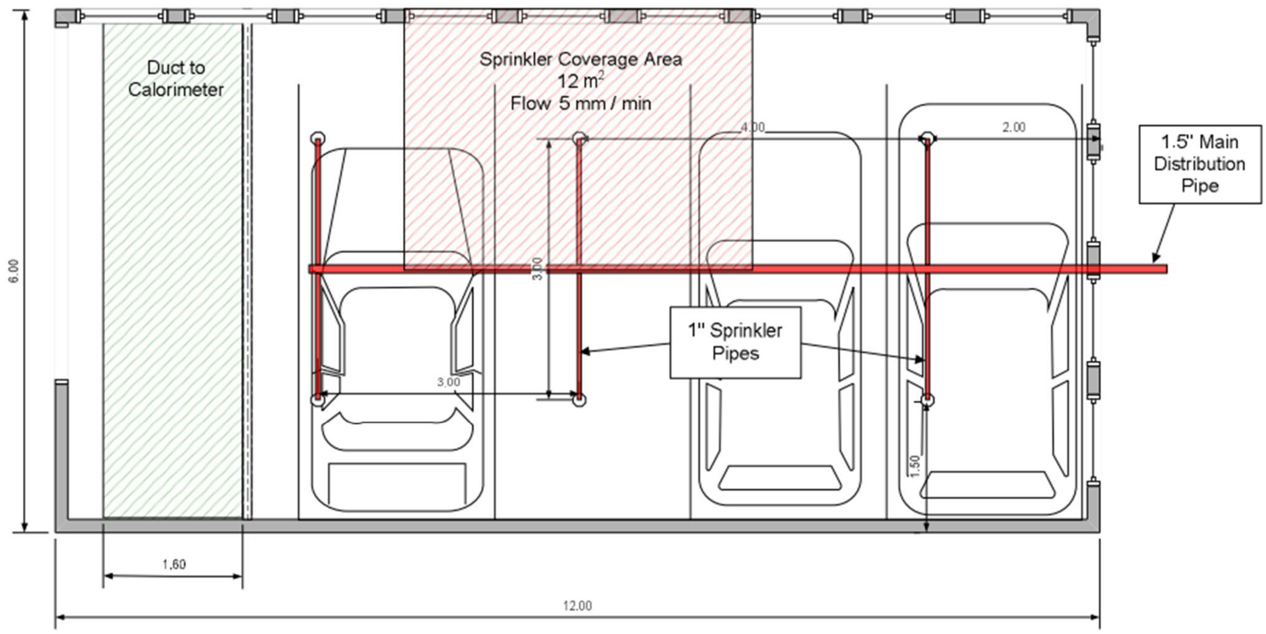


Figure 29. Sprinkler system schematic.

The properties of sprinklers used in the FDS model are given in Table 10.

Table 10. Properties of sprinklers.

Flow rate	60	l/min
Activation temperature	68	˚C
Operating pressure	0.35	bar
Droplet velocity	10	m/s
Spray angle	0-88	˚
Droplet diameter	1000	µm
RTI	150	$(ms)^{½}$

The Model 2 was used for the sprinkler case so that fire spread from one car to another would be possible. Following the results of the FDS model it was found that only the first car ignited. In the test the same result was got. The breaking of windows was as shown in Table 11.

Table 11. Breaking of windows in the sprinkler test.

Blue car window breaking	Model 2, seconds
Right	Open
Left	390
Front	540
Back	460
Yellow car window breaking	
Right	-
Left	-
Front	-
Back	-
Grey car window breaking	
Right	-
Left	-
Front	-
Back	-

The first sprinkler was activated after 292 s from the beginning of the test according to the FDS model. In the experimental test the first sprinkler activated after 241 s from ignition, next ones 246, 2532, 2545, 2701, 2715 s, so in the test all six sprinklers activated. The FDS model analysis was stopped after 30 minutes computing.

The HRR curve in the FDS model is shown in Fig. 30.

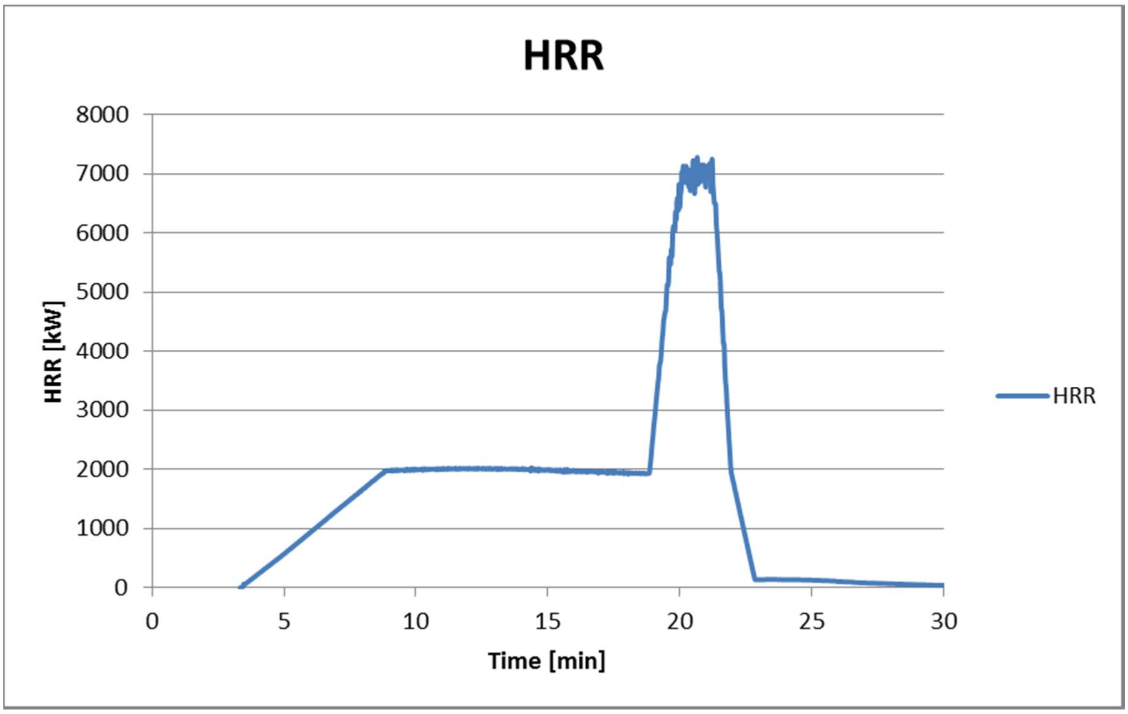


Figure 30. HRR curve in FDS model with sprinklers.

The temperatures in trees based on the FDS results are shown in Figs. 31-33.

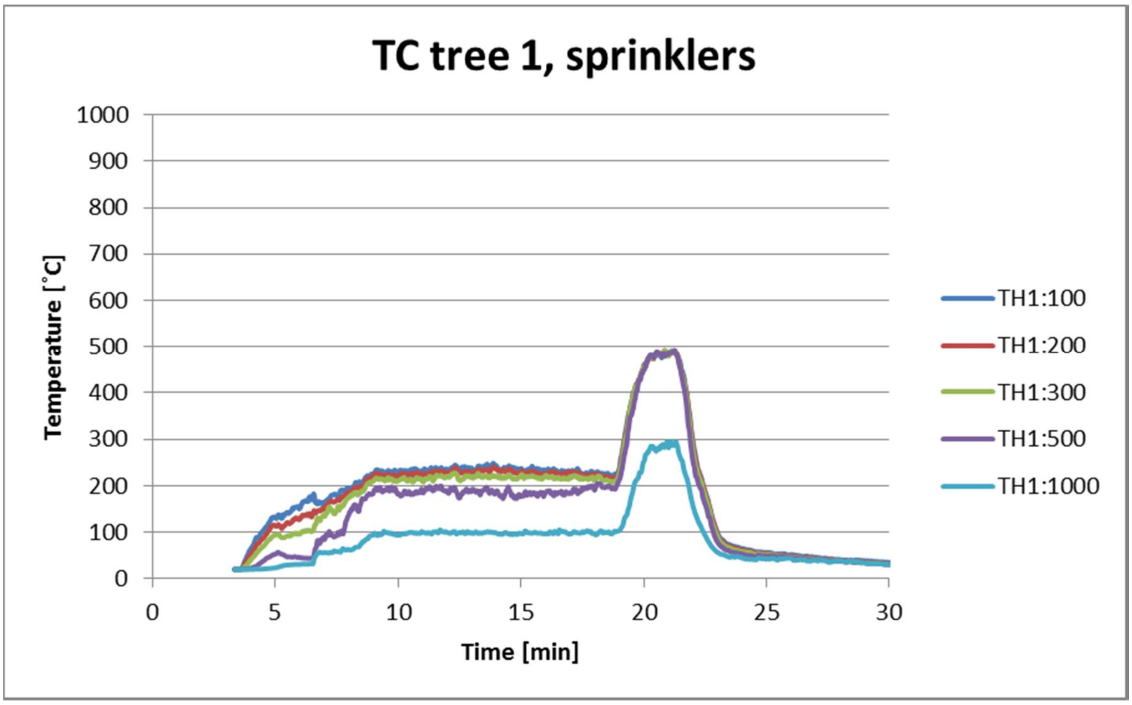


Figure 31. Temperatures in tree 1 with sprinklers.

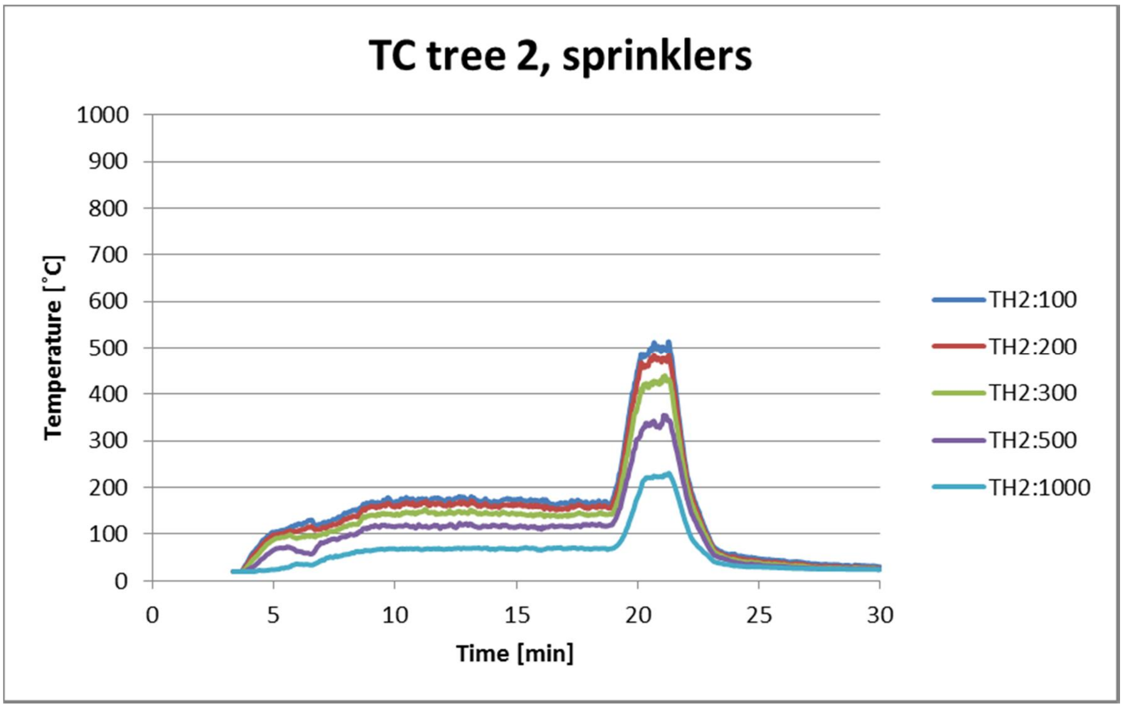


Figure 32. Temperatures in tree 2 with sprinklers.

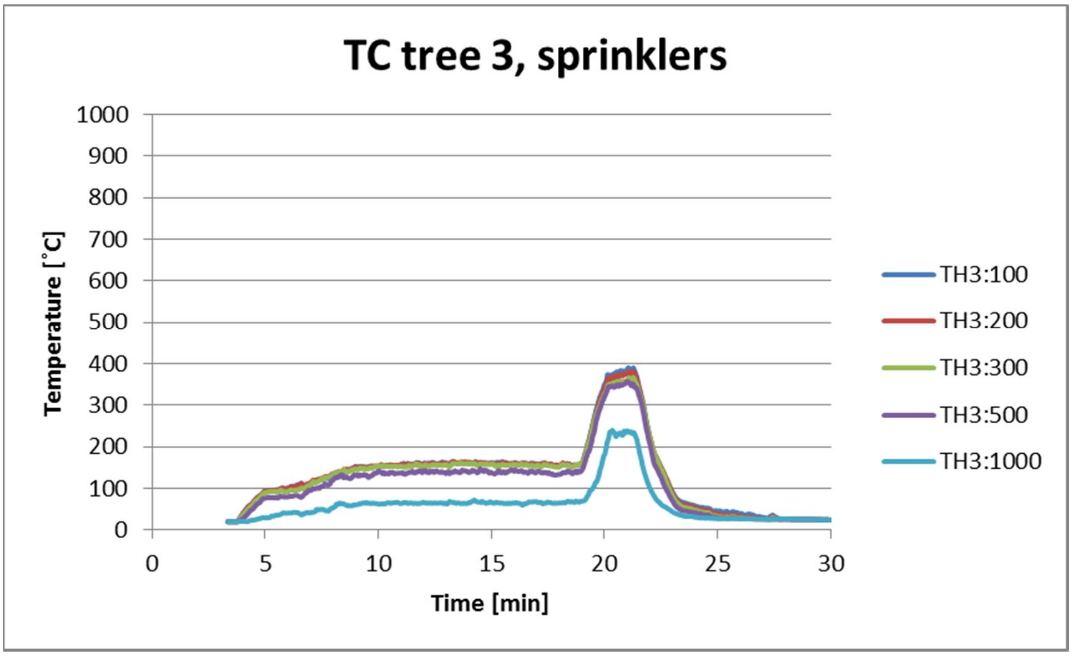


Figure 33. Temperatures in tree 3 with sprinklers.

It can be seen that the maximum temperatures are about 500 ^{o}C. The temperatures in trees measured in the test are shown in Figs. 34-36.

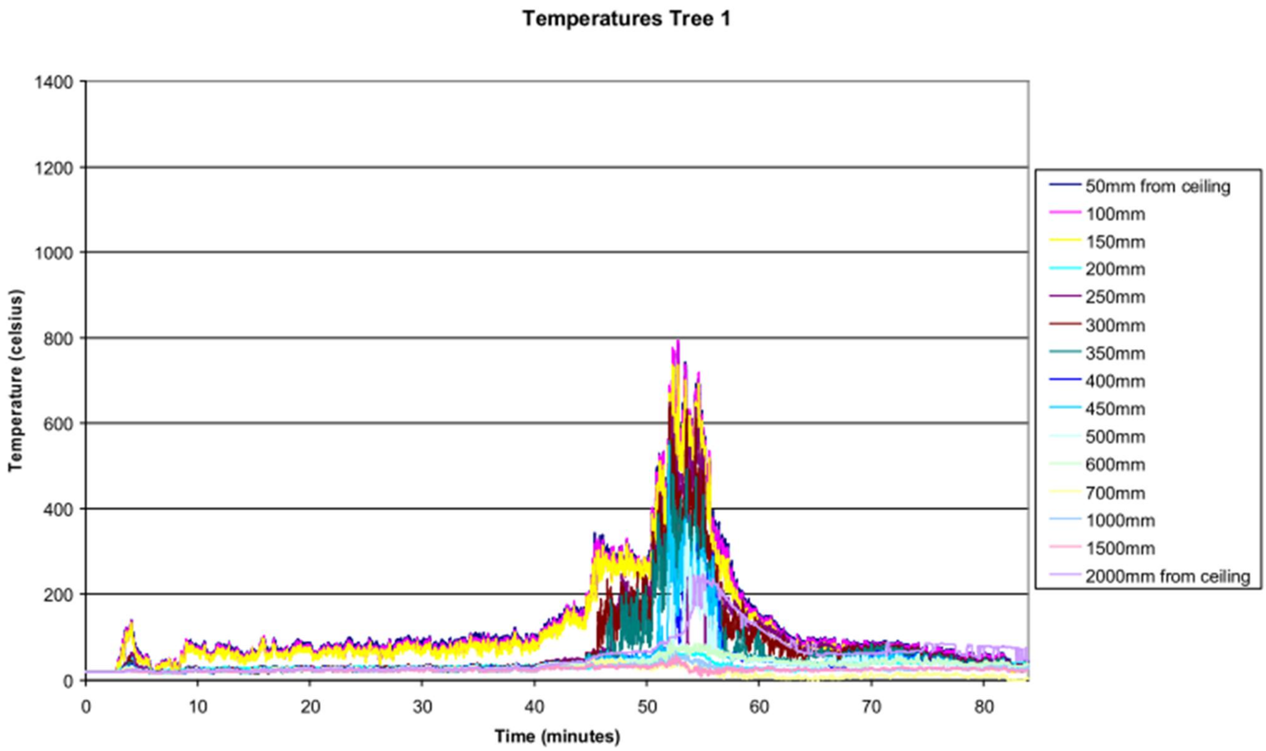


Figure 34. Temperatures in tree 1 in test.

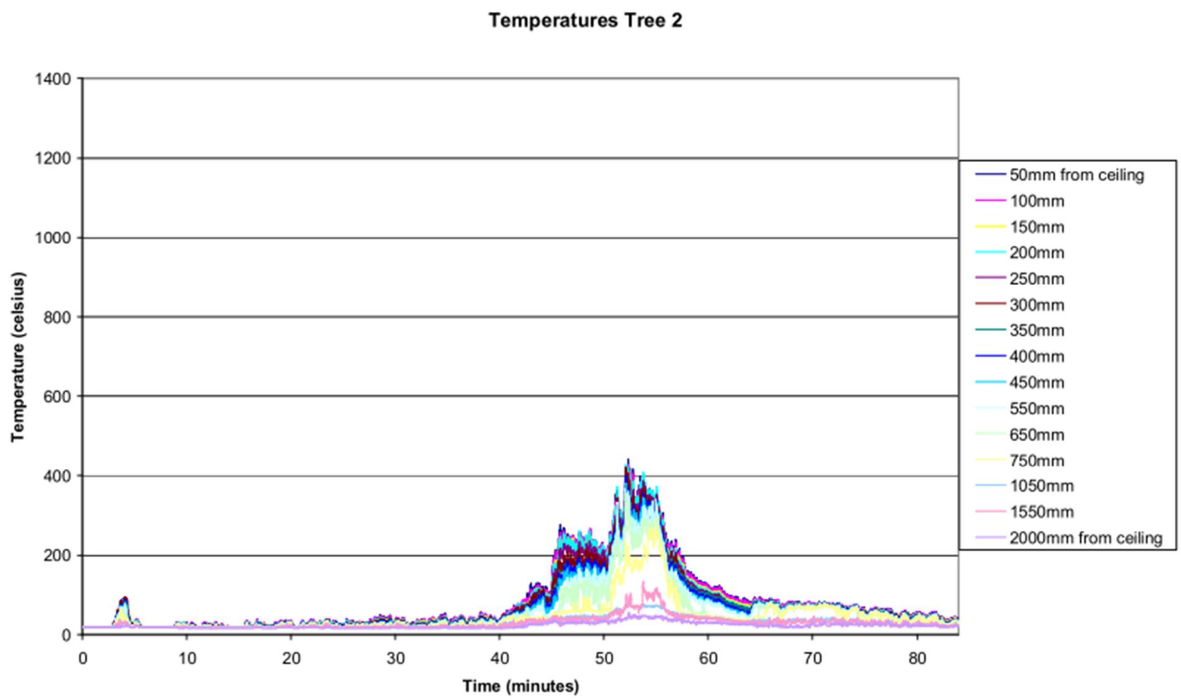


Figure 35. Temperatures in tree 2 in test.

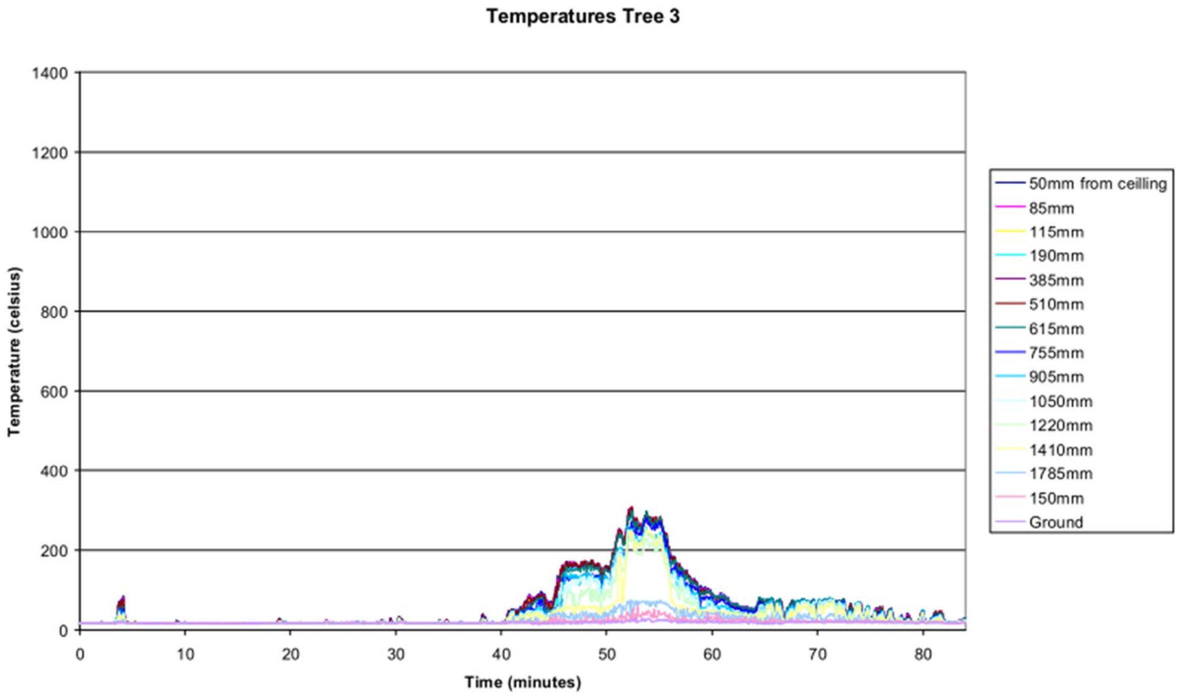


Figure 36. Temperatures in tree 3 in test.

It can be seen that in the test the maximum temperatures in the tree were almost 800 ^{o}C during short times and in the tree 2 about 400 ^{o}C and in the tree 3 about 300 ^{o}C. The cars in the FDS model were category 2 cars. In the test two cars, Renault Grand Escape and Land Rover Freelancer, should be categorized as the category 5 cars. This may explain the difference in maximum temperatures between the simulation and the test. In Table 1 the ratio between the fire loads in category 2 (7500 MJ) and category 5 (12000 MJ) is about the same 12000/7500 = 1.6, as is the difference in the maximum temperatures 800/500 = 1.6.

As a conclusion it can be said the FDS model simulates rather well the test.

Virtual car park simulation with Eurocode factor

Three adjacent cars in a virtual car park were modeled as shown in Fig. 37.

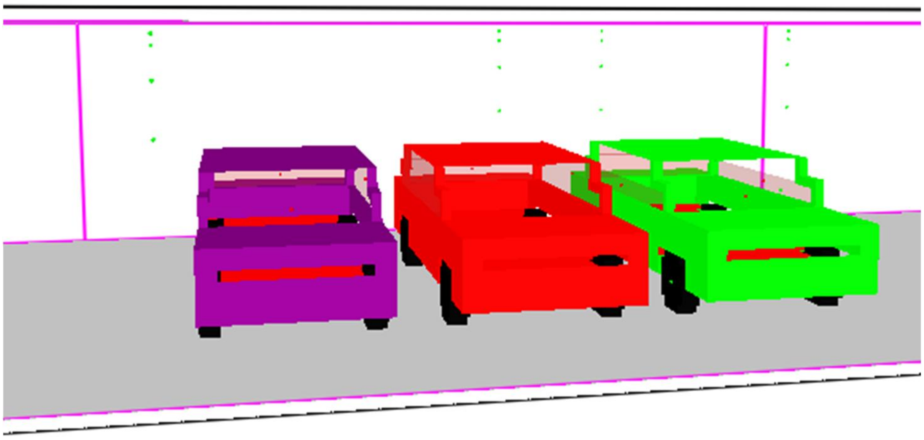


Figure 37. Three adjacent cars.

The sizes of cars are 1.8 x 4.8 m^2. The properties of the cars and their component were as described above. All cars were the category 2 cars. The computational space is 8 x 16 m^2 with free height of 3 m and the cars are located at the mid of the floor. There are no walls in the space. The properties of the roof and the floor in the model are given in Table 12.

Table 12. Properties of floor and roof.

	Floor and roof
Thickness [m]	0.10
Heat conductivity [W/m*K]	1.37
Specific heat [kJ/(kg*K)]	0.88
Density [kg/m3]	2400
Reference	[SFPE, 2002]

Four thermocouple trees are located in the model as shown in Fig. 38.

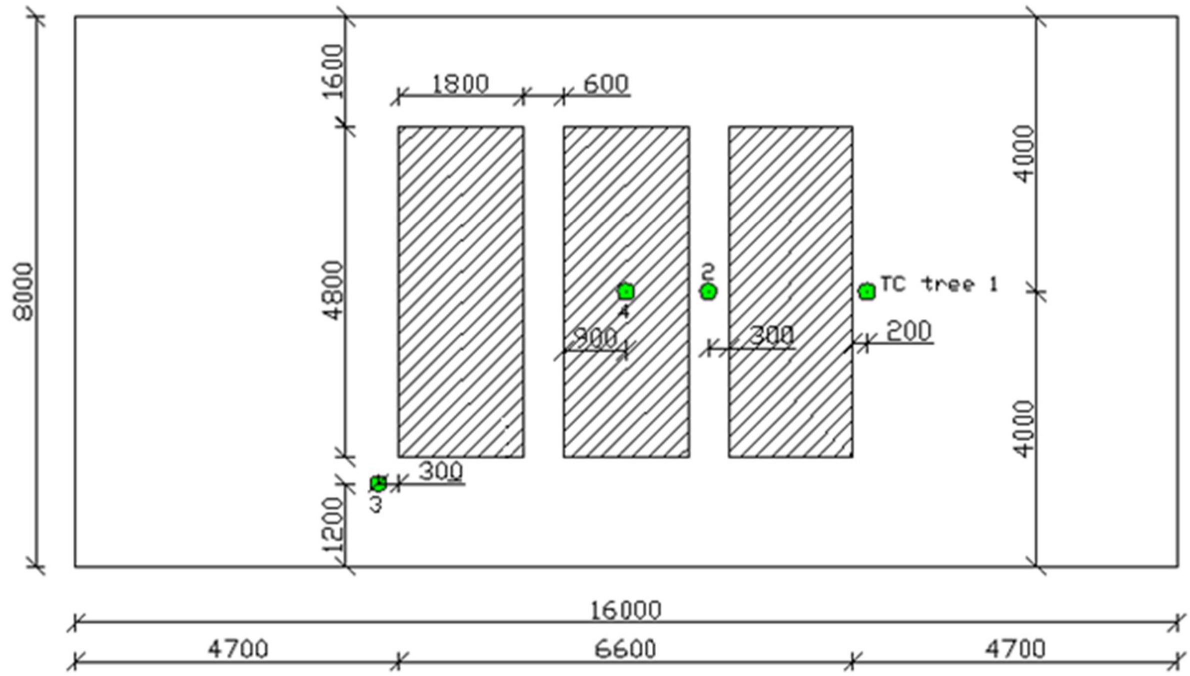


Figure 38. Thermocouples in the model.

In each tree are four thermocouples located at 100, 200, 500 and 1000 mm from the ceiling = bottom level of the roof. The fire starts at the green car of Fig 37.
Seven simulations were done using this FDS model. They were:

1. Model 1, pre-set ignition times for adjacent cars (720 and 1440 s) without sprinklers;
2. Model 2, ignition based on material properties of the cars without sprinklers;
3. Model 3, plane models for cars without sprinklers;
4. Model 2 with sprinklers;
5. Model 2 without sprinkler and reducing released energy (MJ) up to 43 % from the original, meaning 56 % of the heat release rate per unit area (HRRPUA, kW/m^2) from the original;
6. Model 2 without sprinkler and reducing released energy (MJ) up to 53 % from the original, meaning 64 % of the heat release rate per unit area (HRRPUA, kW/m^2) from the original;
7. Model 2 without sprinkler and reducing released energy (MJ) up to 61 % from the original, meaning 69 % of the heat release rate per unit area (HRRPUA, kW/m^2) from the original.

The simulation number 7 corresponds to the Eurocode case: automatic water extinguishing system reduces by the factor 0.61 and there are 0 independent water supplies. In the FDS model this reduction was completed by reducing with the factor 0.69 the given peak HRRPUA value of the burning plane inside the car, and by the numerical integration was calculated the released energy, which was with this value 0.61 times the original energy. The same technique was used in the simulations 5 and 6.
The computing times recorded in this study using the hardware specification above were:

- Grid size 100 x 100 x 100 mm^3 at the entire computing space, cubical elements total amount 409600, resolution 25, total CPU 130 hours without sprinklers;
- If grid size 200 x 200 x 200 mm^3 used at the edges of the computing space, 3 meters from both edges, total amount cubical of elements 265600, total CPU 78 hours without sprinklers. No significant differences in thermocouple tree temperatures compared with 409600 elements;
- Using this smaller amount of elements the total CPU 112 hours with sprinklers.

In this case, for some reasons, the Model 3 did not work well, giving far too low temperatures compared to the temperatures given by the Model 1 and 2 in the tree number 1. In the following are reported only the results of the Model 1 and 2. The ignition times in the Model 2 (simulation number 2) were 725 and 1443 s matching well to preset ignition times 720 and 1440 s in the Model 1 (simulation number 1).

The HRR curves for the simulations 1 and 2 are presented in Figs. 39 and 40.

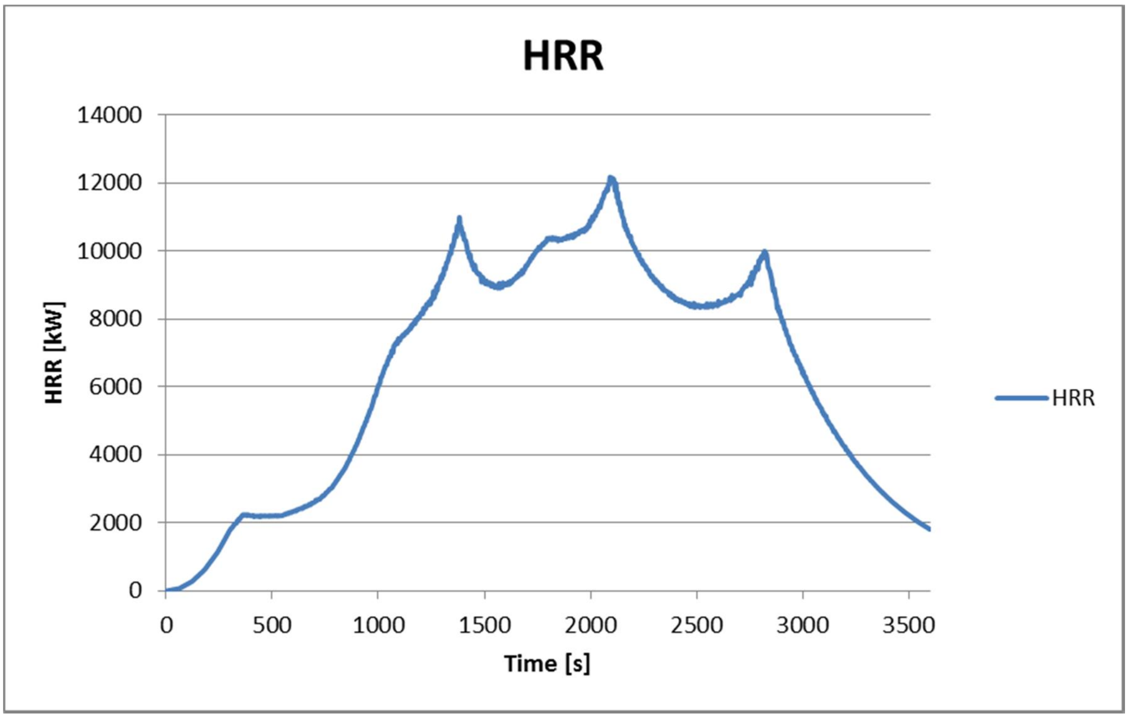


Figure 39. HRR curve for simulation 1.

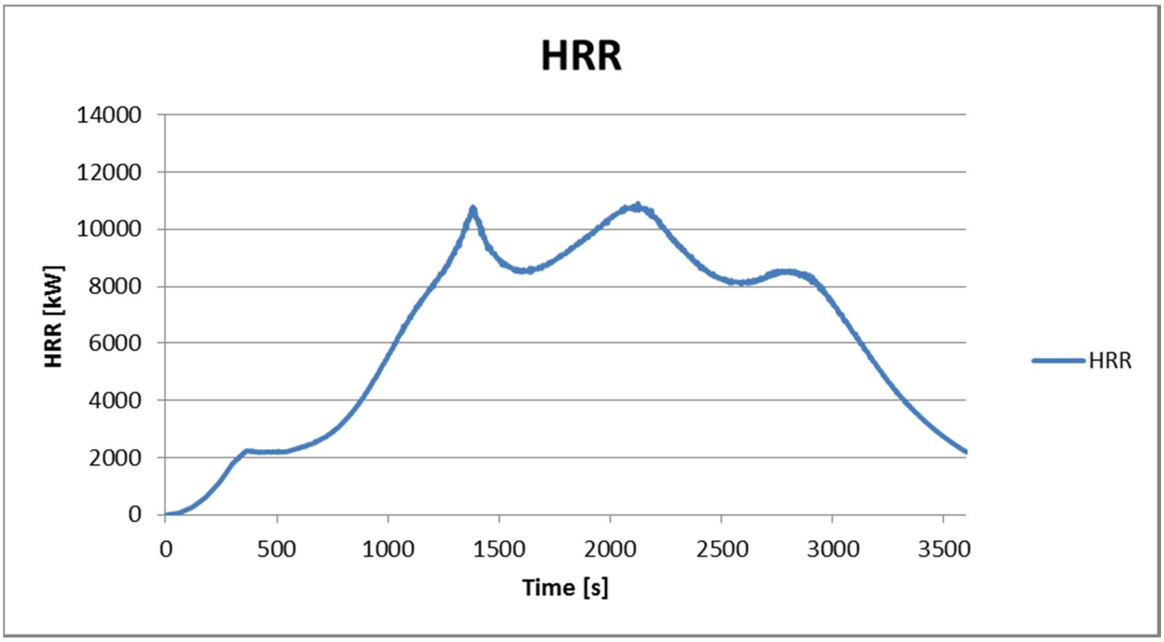


Figure 40. HRR curve for simulation 2.

The temperatures in four trees of the Model 1 and 2 are presented in Figs. 41-48.

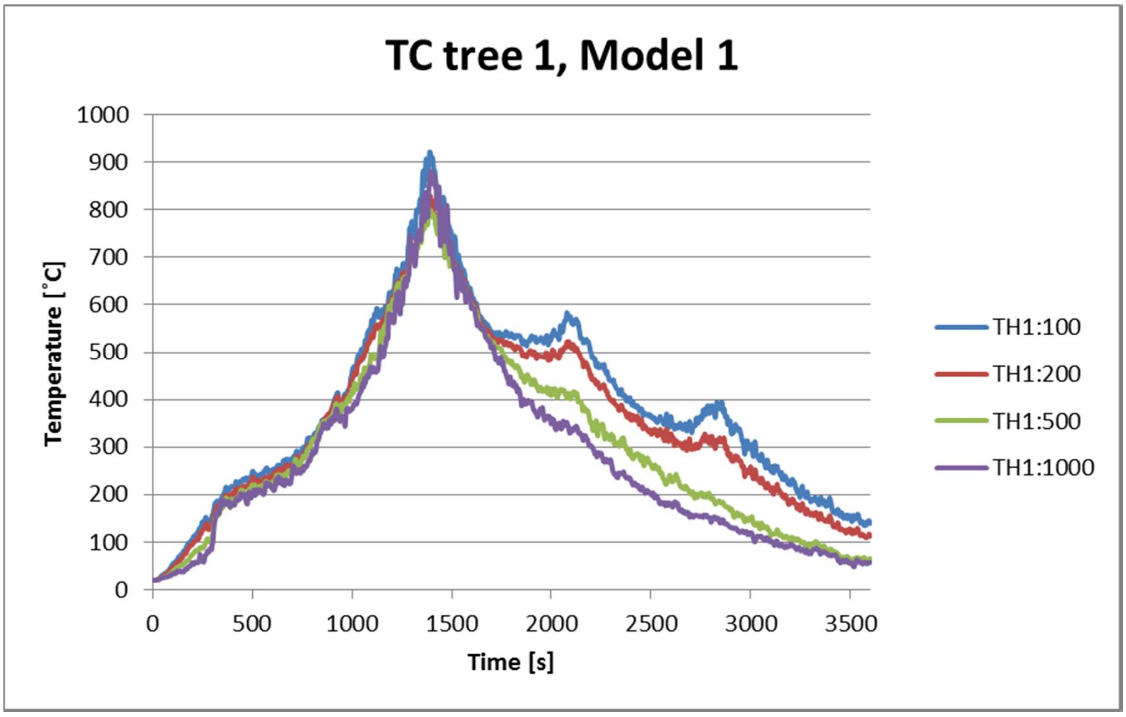


Figure 41. Temperatures of tree 1 in Model 1.

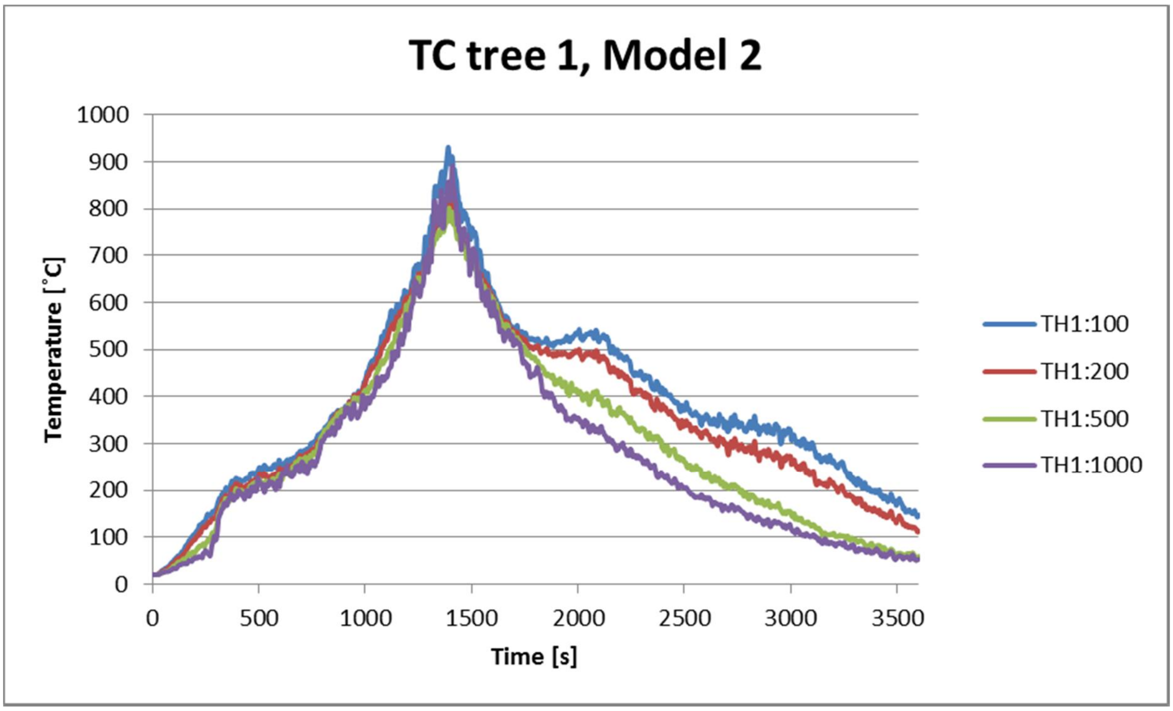


Figure 42. Temperatures of tree 1 in Model 2.

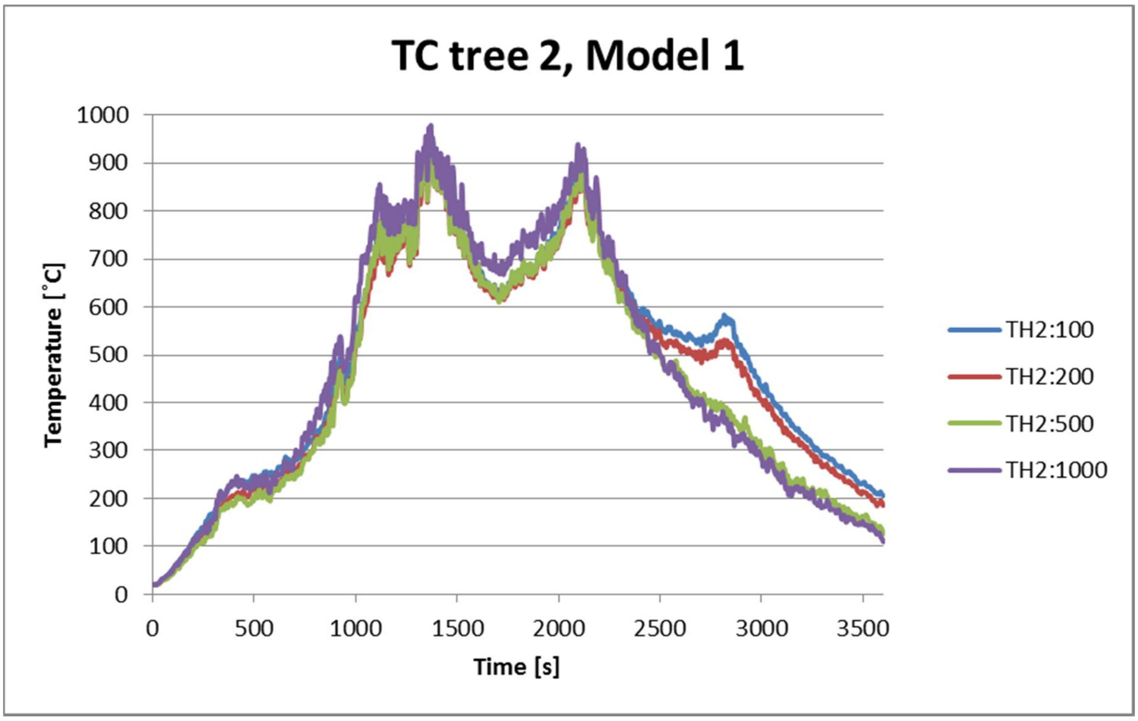


Figure 43. Temperatures of tree 2 in Model 1.

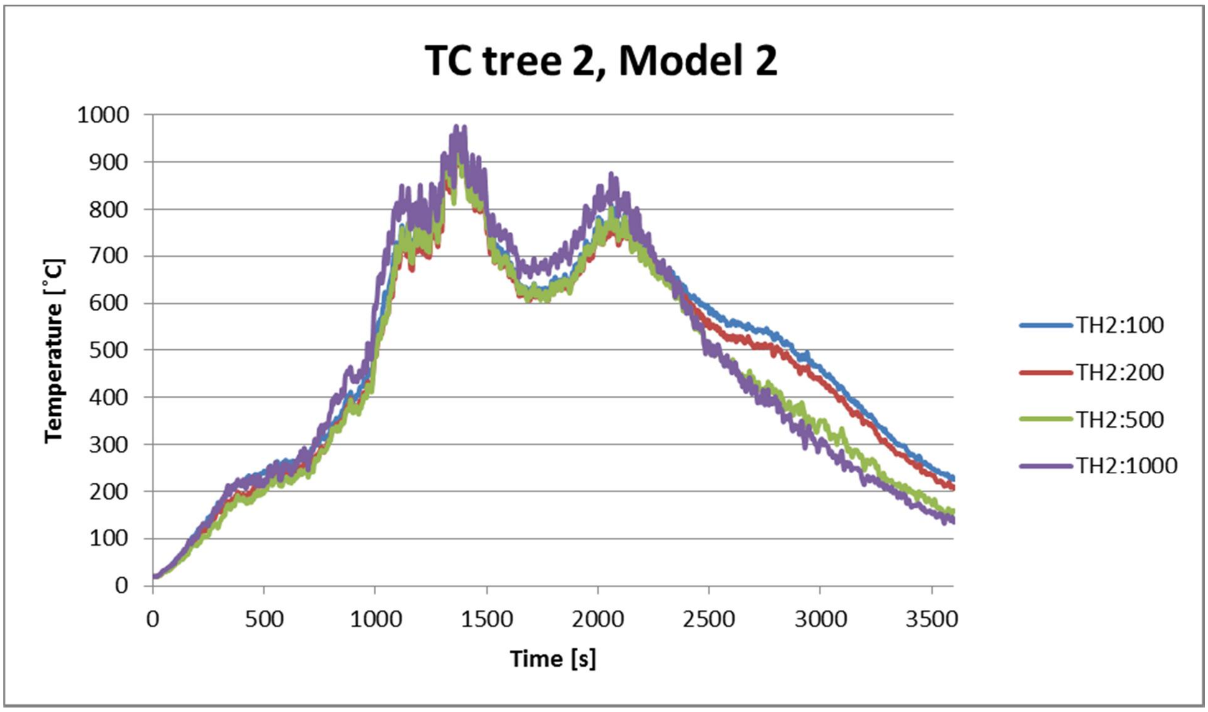


Figure 44. Temperatures of tree 2 in Model 2.

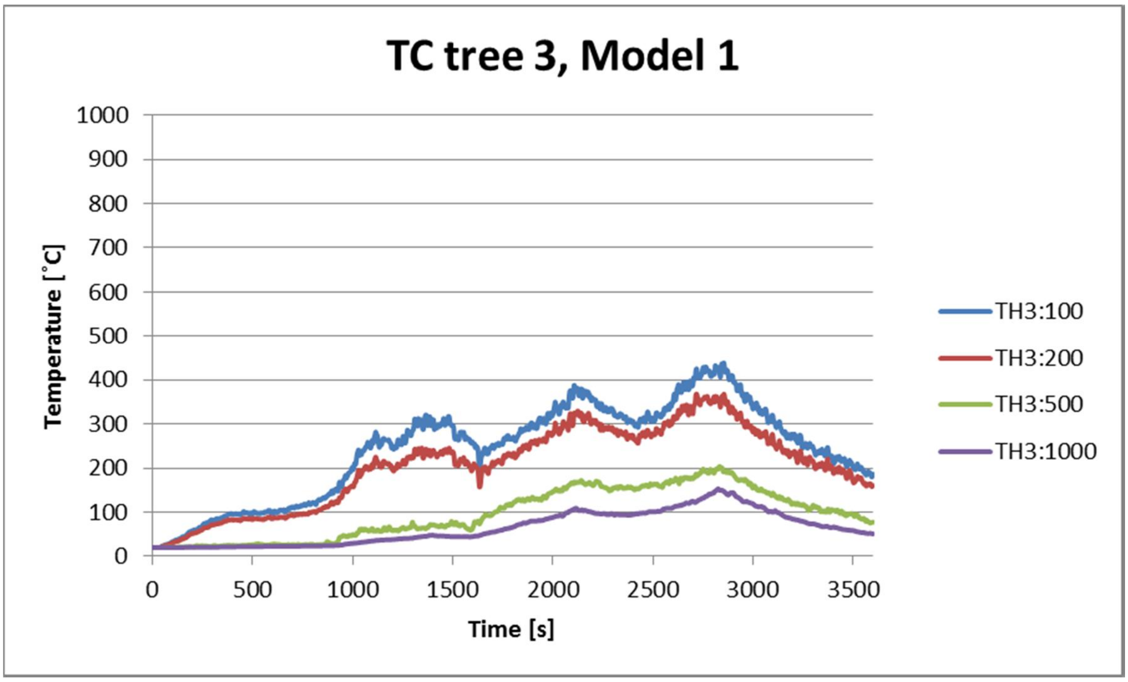


Figure 45. Temperatures of tree 3 in Model 1.

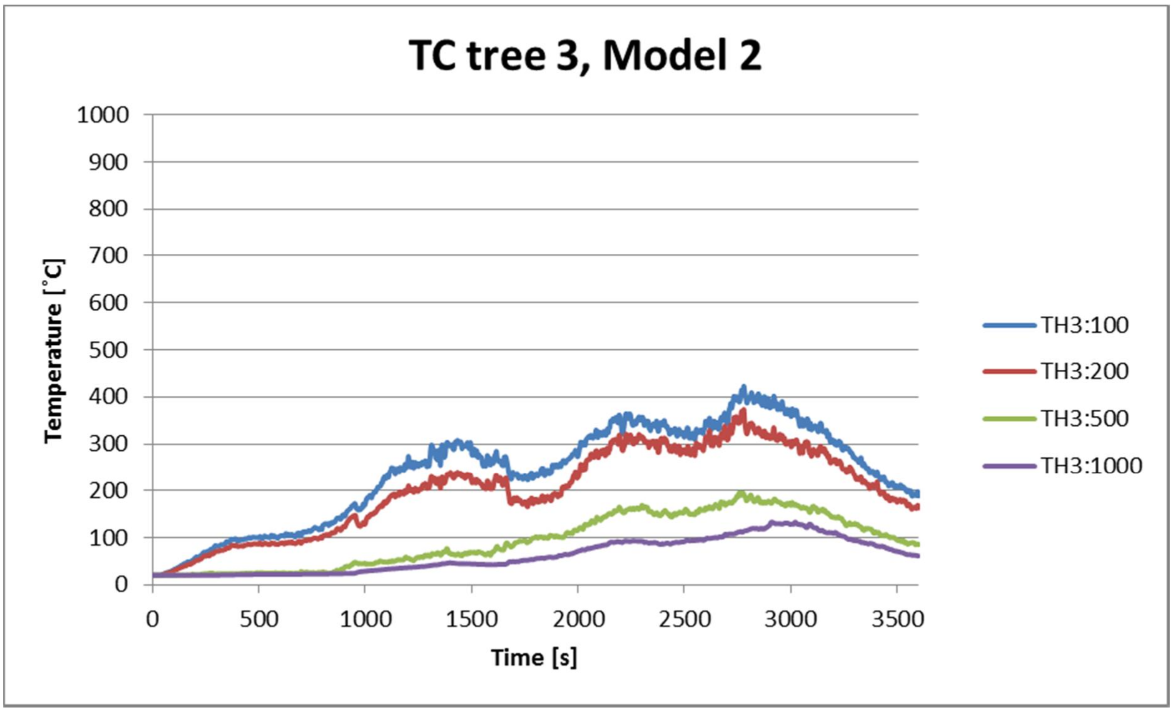


Figure 46. Temperatures of tree 3 in Model 2.

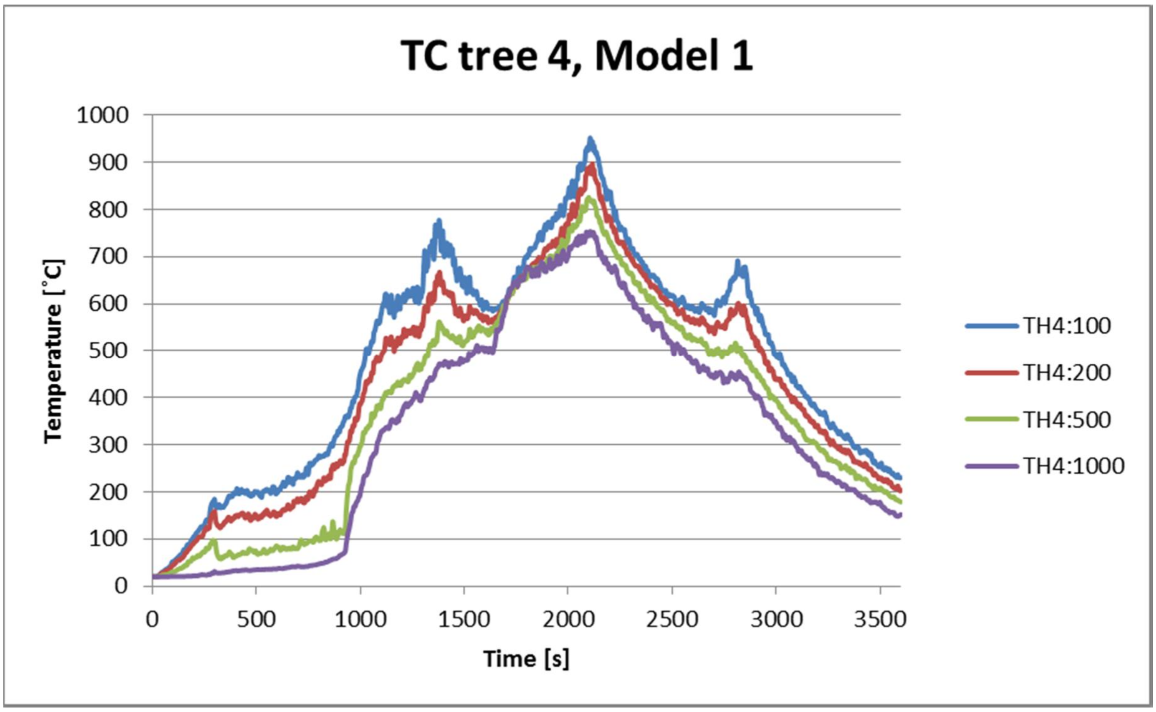


Figure 47. Temperatures of tree 4 in Model 1.

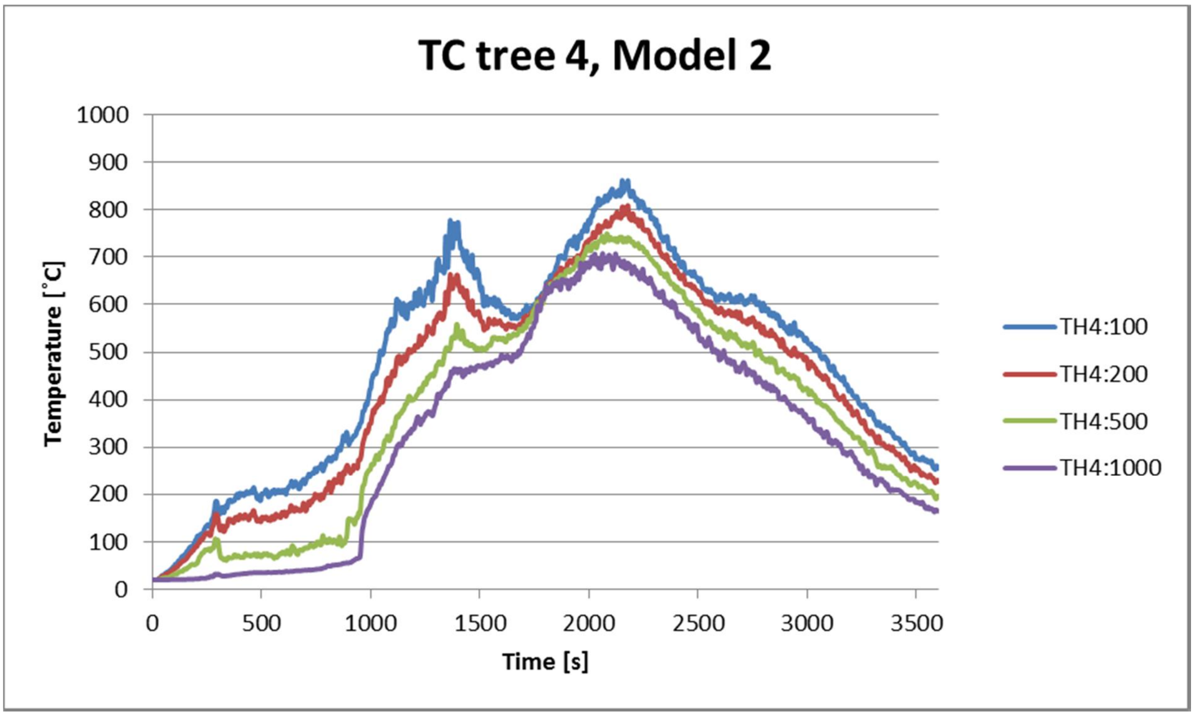


Figure 48. Temperatures of tree 4 in Model 2.

It can be seen that the temperatures are very similar based on the Method 1 and 2. The maximum temperature is about 950 ^{o}C. The breaking of windows in the Models 1 and 2 are given in Table 13.

Table 13. Breaking of windows in Models 1 and 2 in virtual car park case.

Violet car window breaking	Model 1, seconds	Model 2, seconds
Left	273	273
Right	272	273
Front	298	299
Back	291	291
Red car window breaking		
Left	468	470
Right	924	949
Front	925	888
Back	945	951
Green car window breaking		
Left	1090	1127
Right	1632	1650
Front	1591	1597
Back	1624	1659

The Model 1 and 2 gives similar results both validation test and Eurocode factor case. In this context the designer can use the preset ignition times (Model 1) to save time in the car fire simulations if one is modeling fire case scenario without sprinklers. If sprinklers are needed, the designer have to set material parameters and ignition temperatures (Model 2) for objects so that sprinklers can affect fire spread by cooling the material surfaces with droplets. Furthermore, the Model 2 is more realistic based on the ignition activated with the gas temperatures nearby the cars. By these means the designer can take into account the ignition of objects nearby the cars, not only the adjacent cars. However, accurate fixing and adjusting of the car parameters in the Model 2 is time-consuming and needs many test runs to work properly. In FDS there are also some difficulties to set ignition temperatures as high enough as they are in literature so that the spread of fire would happen in same way than in real car fire experiments. These problems may be resulted from too simple car model, which has been solved by reducing the ignition temperatures slightly from recommended values in literature. The Model 2 is used in the next simulations 4 - 7.

Next, the simulation number 4 was done by implementing the sprinklers to the Model 2. The properties of the sprinklers were as given in Table 10, but the flow rate was set to 45 l/min because sprinkler coverage area per head is now 9 m^2. The layout of the sprinklers is given in Fig. 49. Totally 9 sprinklers were implemented to the model.

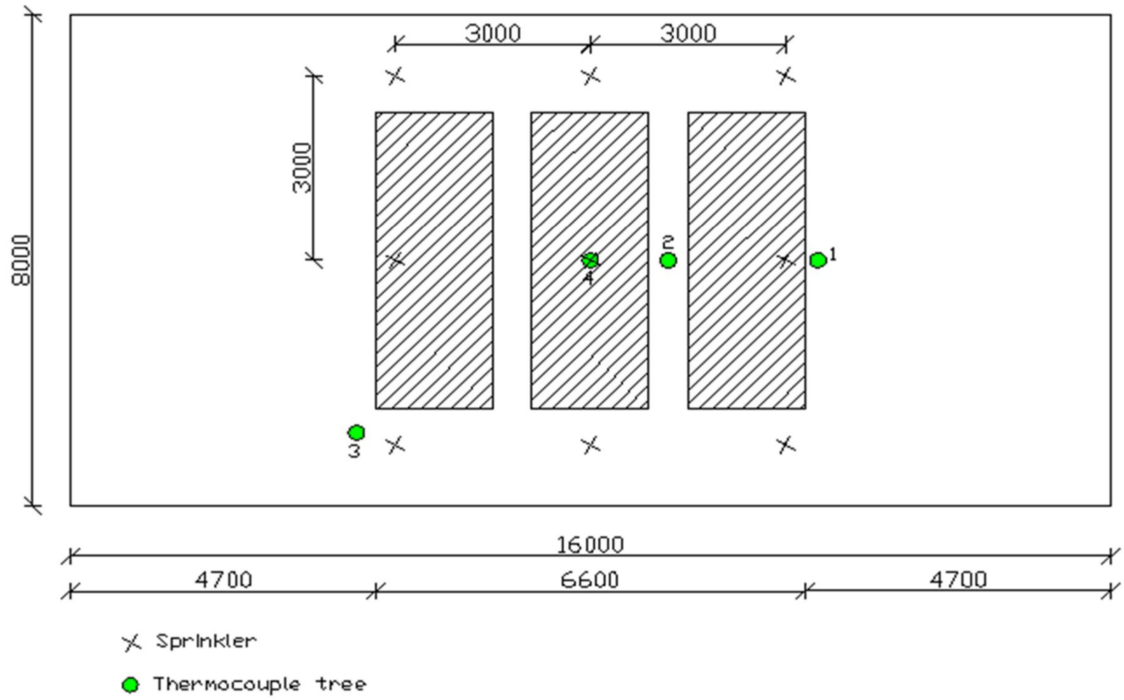


Figure 49. The layout of sprinklers.

In Fig. 49 are shown the locations of thermocouple trees, same as in Fig. 38, and the locations of the sprinklers.

The HRR curves without ("Normal case" in the figure) and with sprinklers are given in Fig. 50.

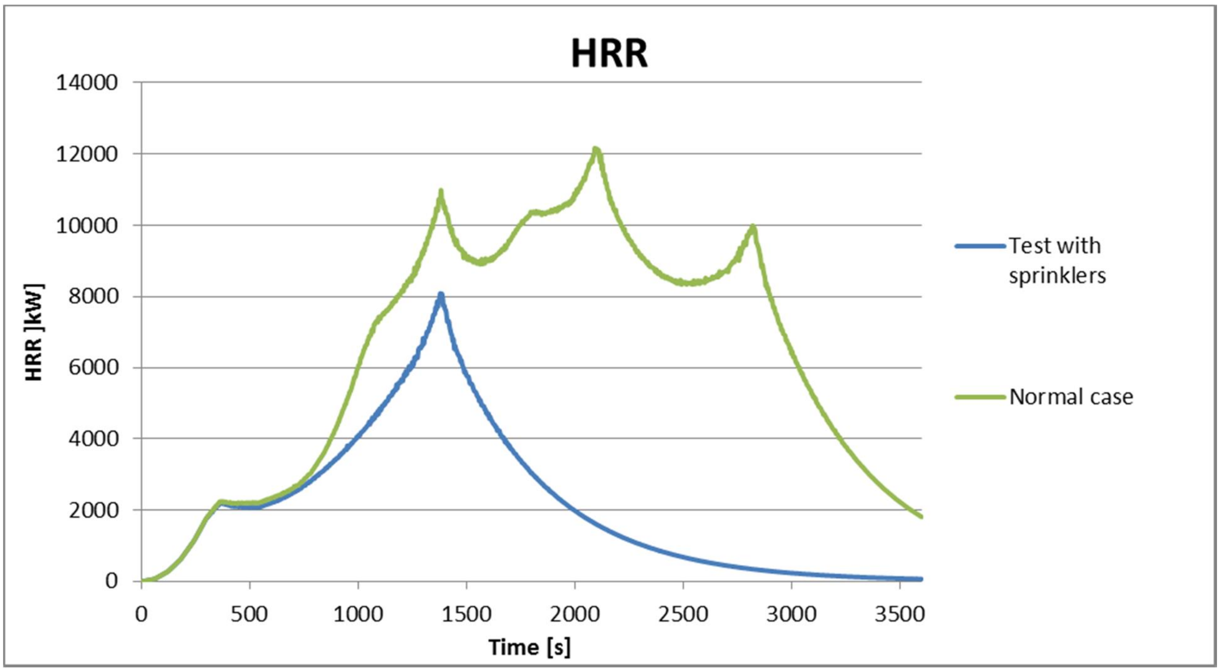


Figure 50. HRR curves with and without (Normal case) sprinklers for three cars.

The first sprinkler in the FDS model was activated in 202 seconds after ignition. Only the first car was ignited in this simulation. After about 20 minutes (1200 s) the HRR curve is decreasing. It is also important to notice that sprinklers do not affect the ramp of heat release rate of the first car. The breakings of windows are given in Table 14.

Table 14. Breaking of windows in sprinkler case according to the FDS model.

Violet car window breaking		Simulation 4, seconds
	Left	275
	Right	277
	Front	298
	Back	301
Red car window breaking		
	Left	-
	Right	-
	Front	-

	Back	-
Green car window breaking		
	Left	-
	Right	-
	Front	-
	Back	-

The temperatures in four trees are shown in Figs. 51- 54 recorded in the simulation 4.

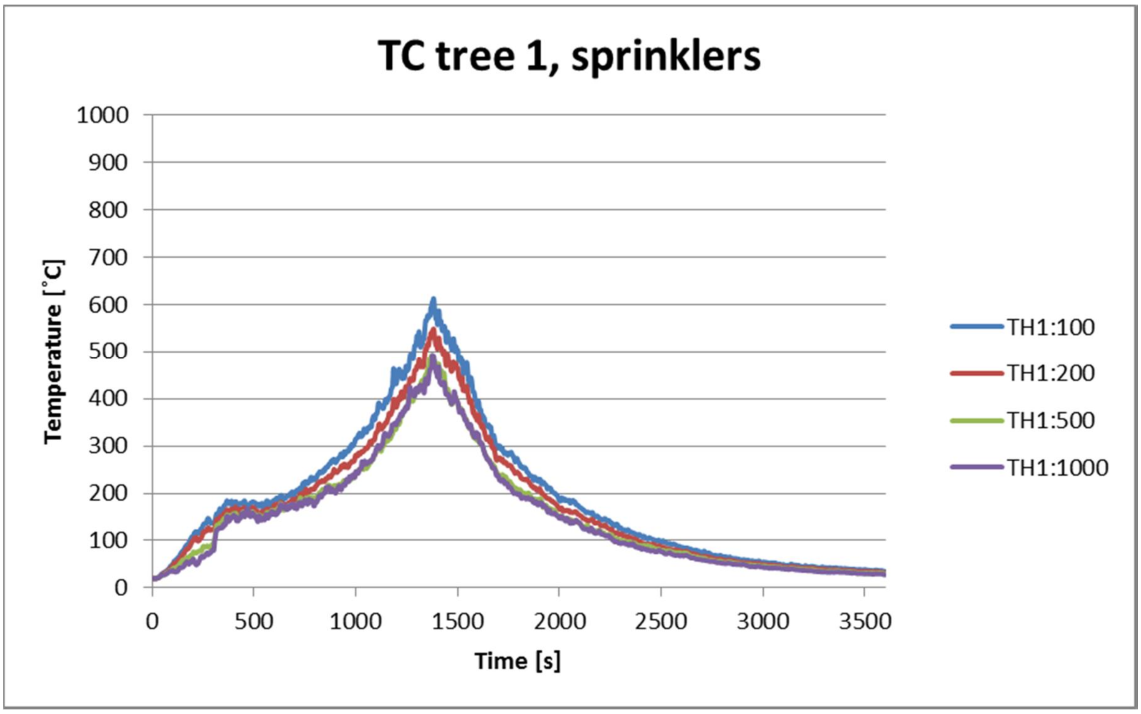


Figure 51. Temperatures in tree 1 with sprinklers.

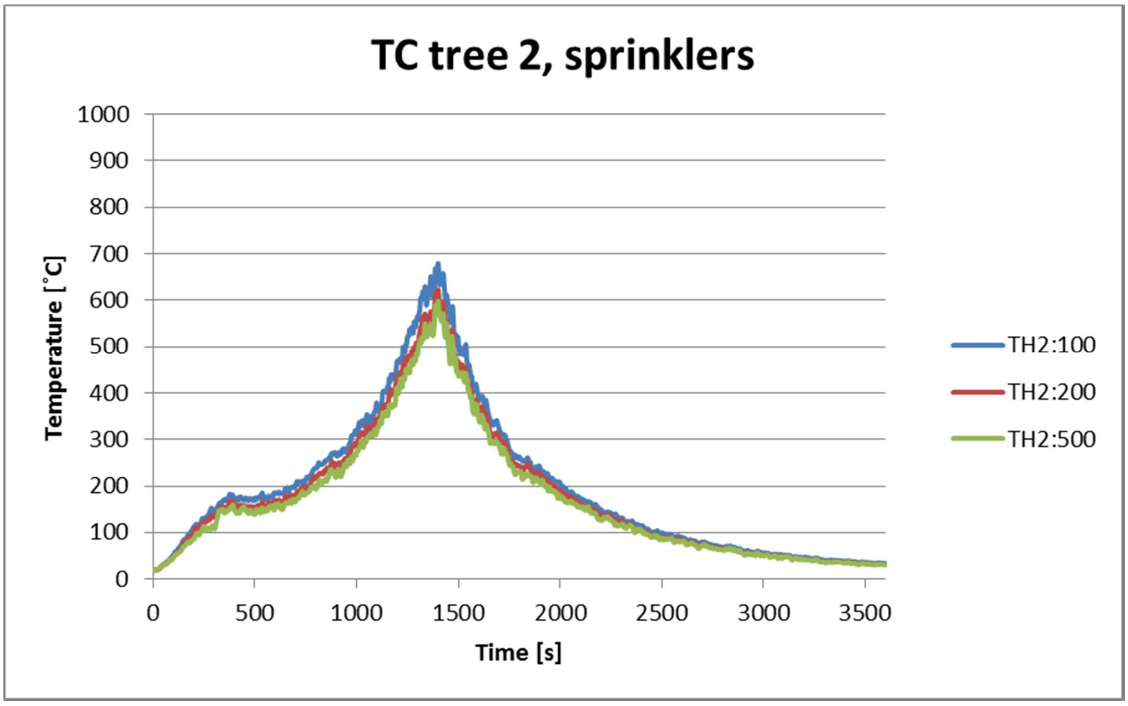


Figure 52. Temperatures in tree 2 with sprinklers.

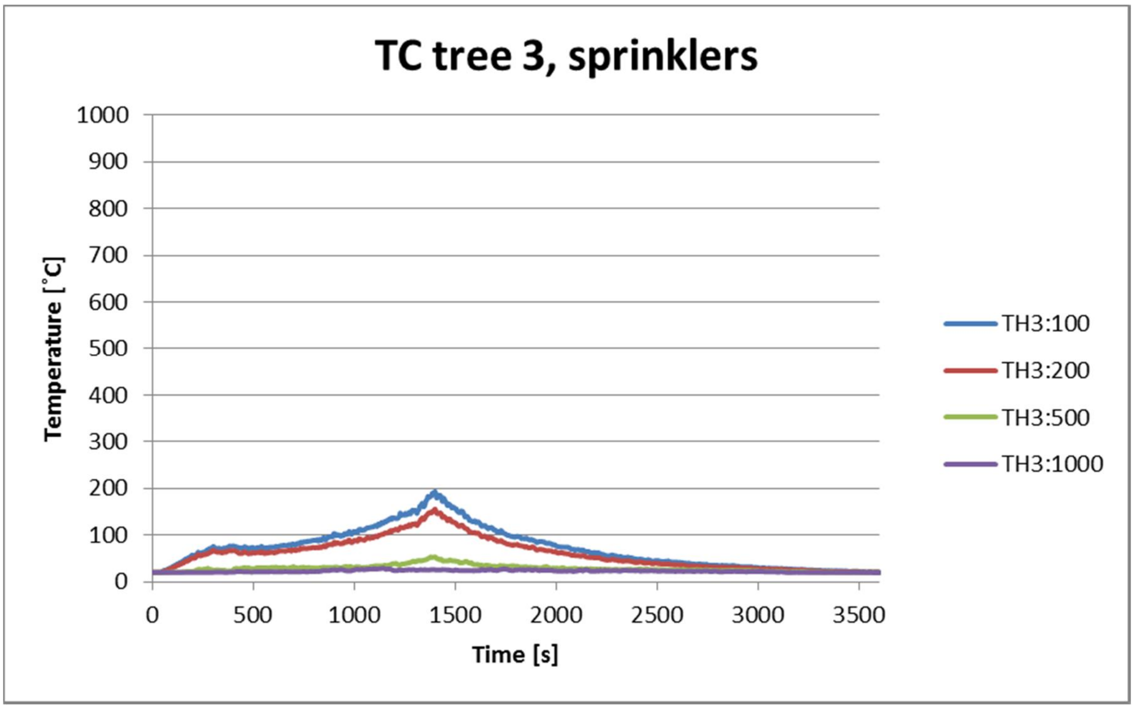


Figure 53. Temperatures in tree 3 with sprinklers

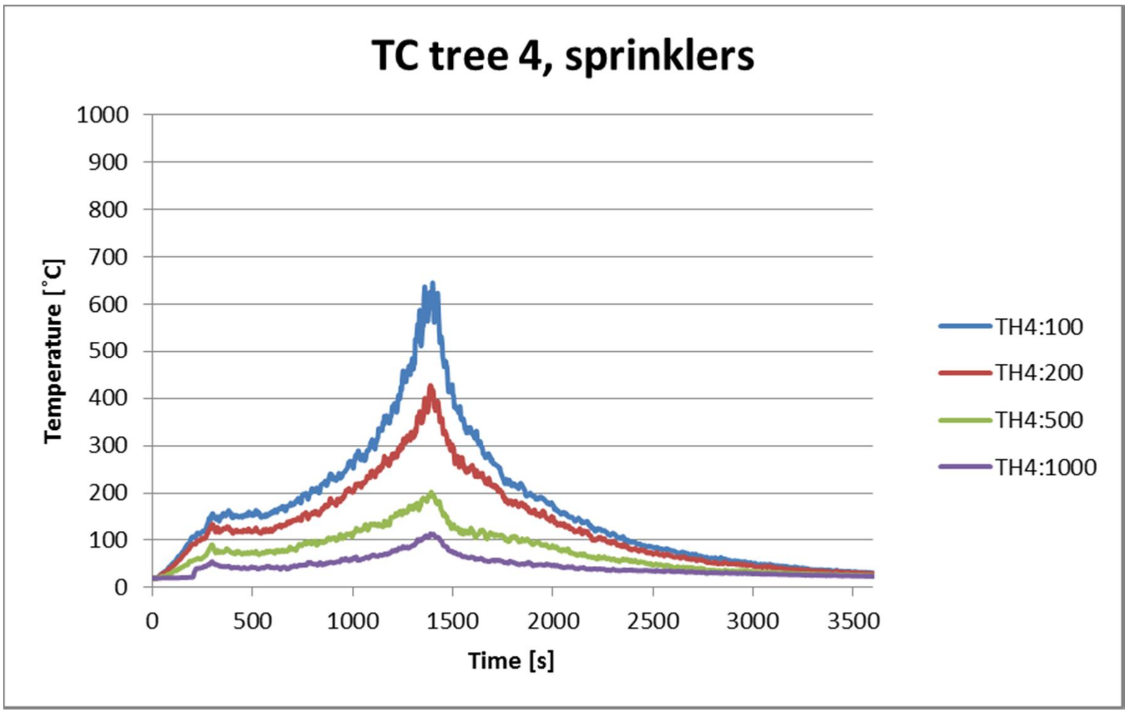


Figure 54. Temperatures in tree 4 with sprinklers.

It can be seen that the maximum temperatures are lower than in the case without sprinklers, as was expected. The maximum temperature without sprinklers was about 970 ^{o}C (Figs. 43 and 44) and with sprinklers about 670 ^{o}C (Fig. 52).

Next, the results of the simulations 5, 6 and 7 are given. The used HRR curves in these cases are shown in Figs. 55-57. Theoretical reduction calculations of the fire load are based on the ideal fire scenario alias simulation 1. For example in the “EC 0,43” case the reduction was completed by reducing with the factor 0.56 the given peak HRRPUA value of the burning plane inside the car, and by the numerical integration was calculated the released energy, which is with this value 0.43 times the original energy. For this reason comparable heat release rate (Figs 55 – 57) and temperature curves (Figs 70 -74) from Model 1 are used called “Normal case”. However, the FDS input file of the simulation model is based on the Model 2 because ignition of the second and the third car have to be independent of time. In practice the idea is the same when implementing real sprinklers.

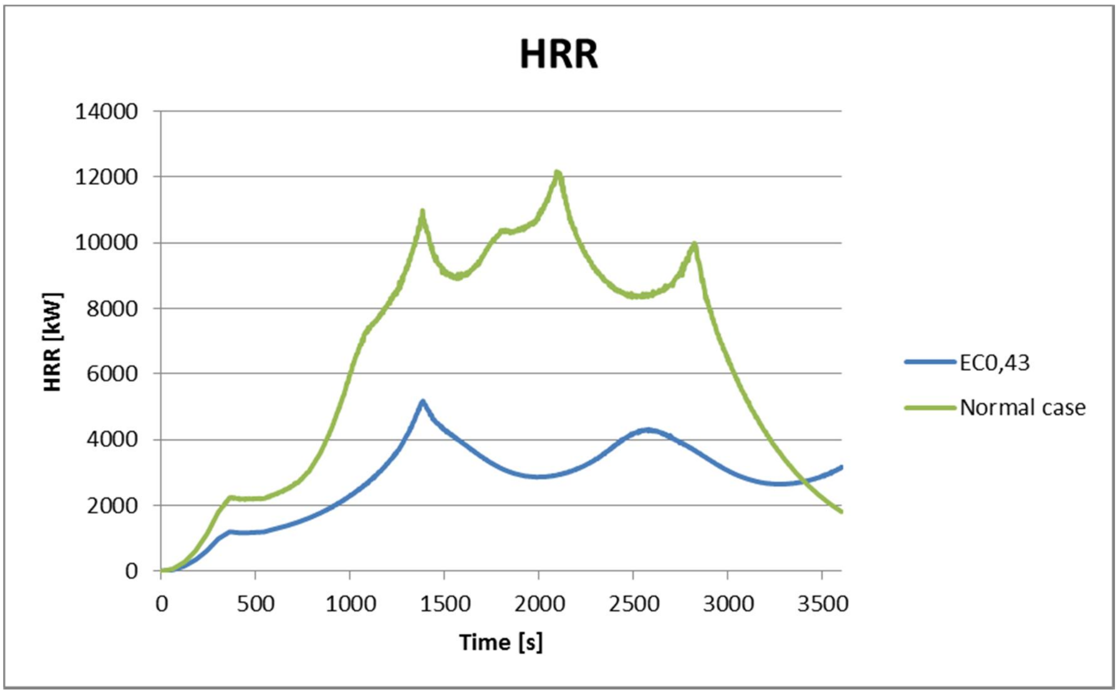


Figure 55. HRR with fire load reduction 0.43.

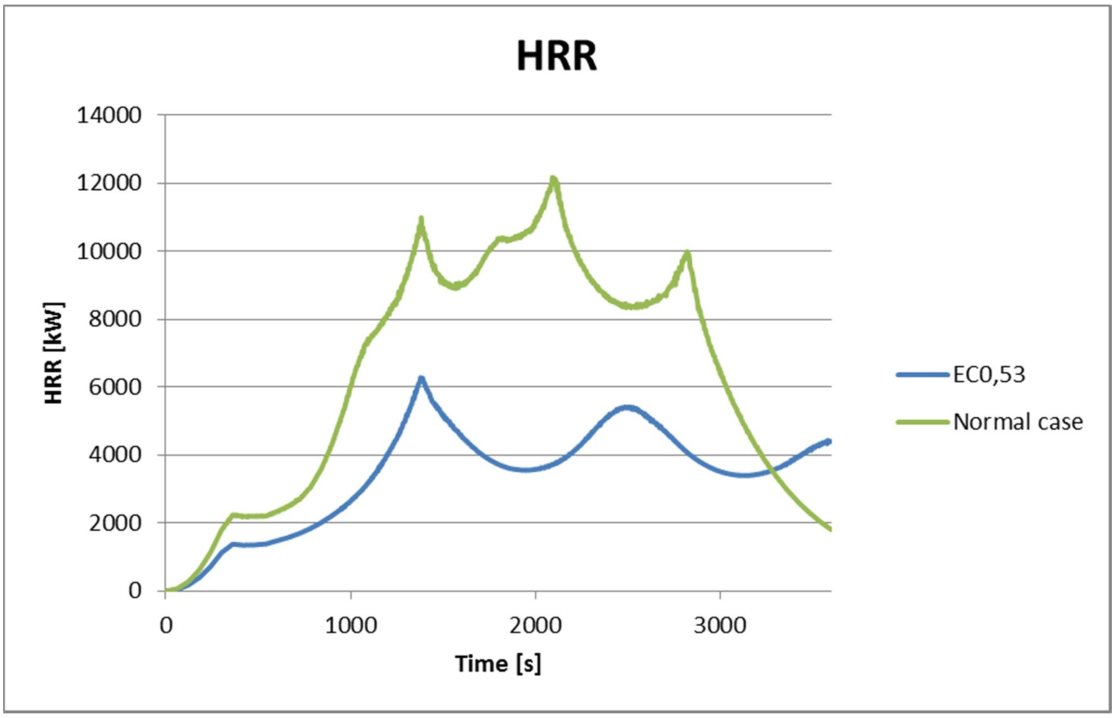


Figure 56. HRR with fire load reduction 0.53.

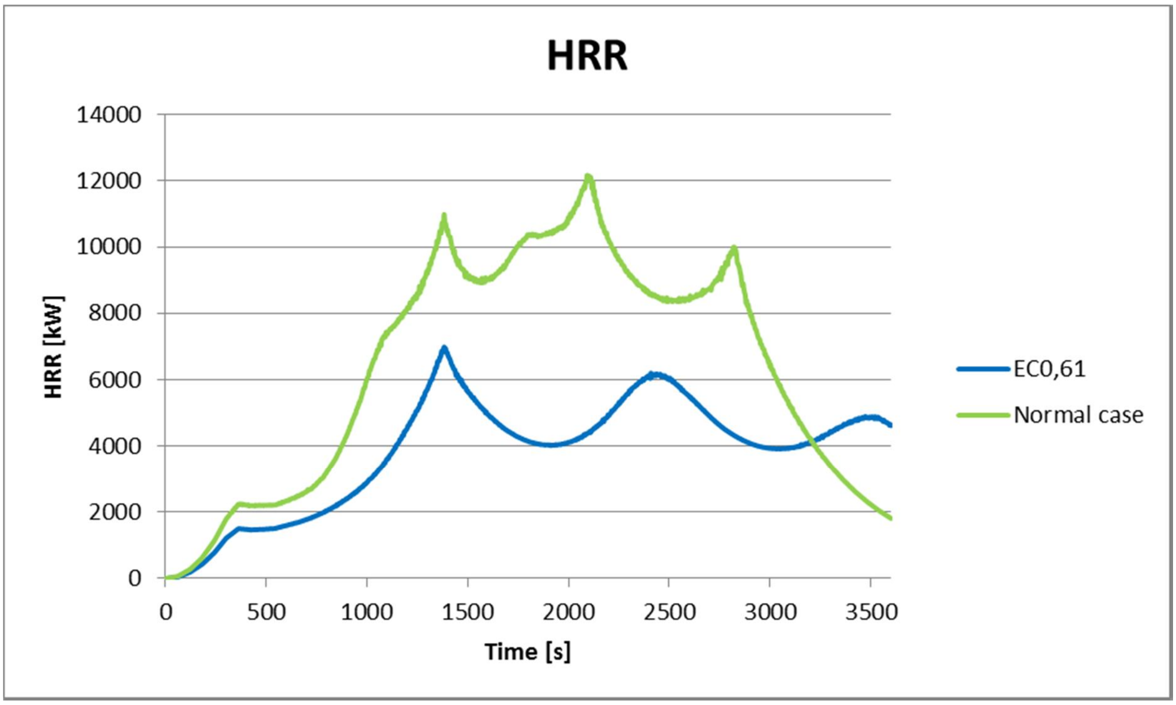


Figure 57. HRR with fire load reduction 0.61.

It can be seen, that these models do not take into account that the adjacent cars do not ignite with sprinklers, as was the case in the simulation 3 and in the BRE test. However, the maximum temperatures are the criteria in our case.

The temperatures in the trees 1-4 are shown in Figs. 58–69 in simulations 5-7.

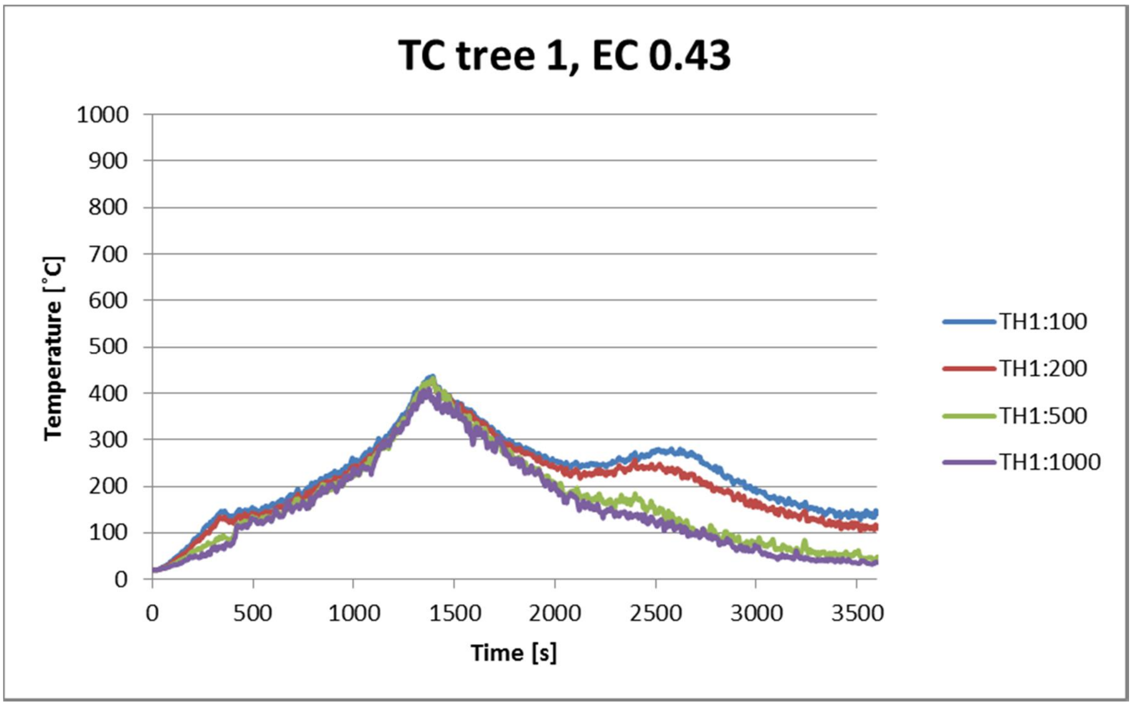


Figure 58. Temperatures in tree 1 in simulation 5.

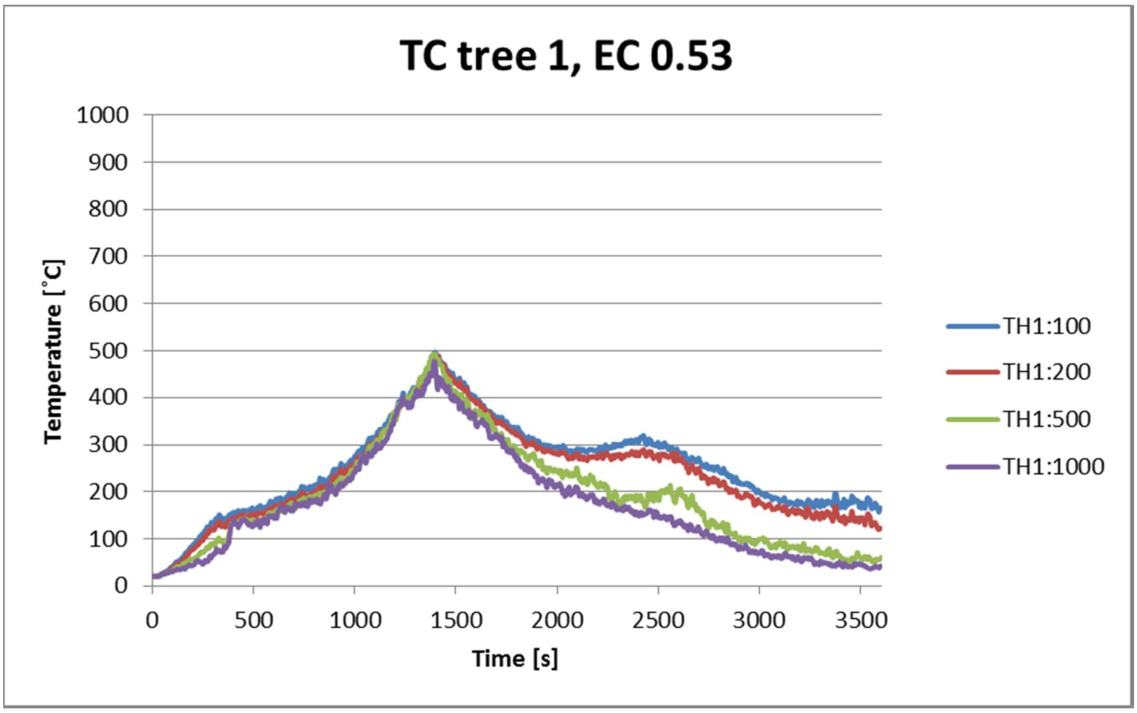


Figure 59. Temperatures in tree 1 in simulation 6.

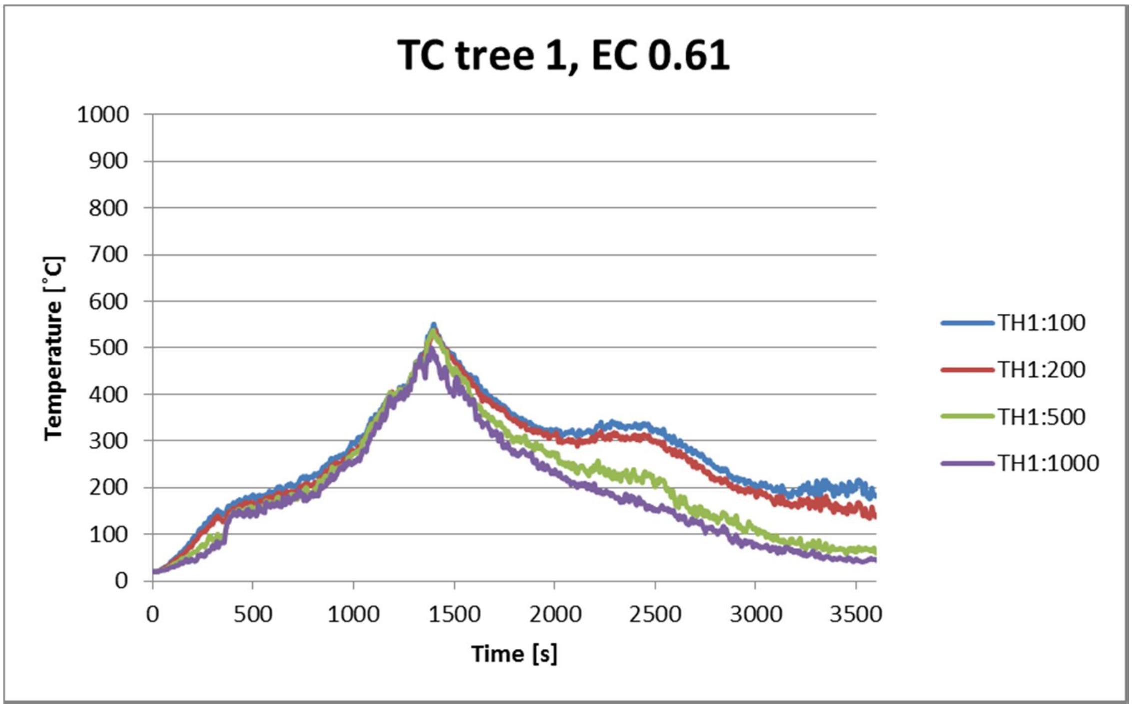


Figure 60. Temperatures in tree 1 in simulation 7.

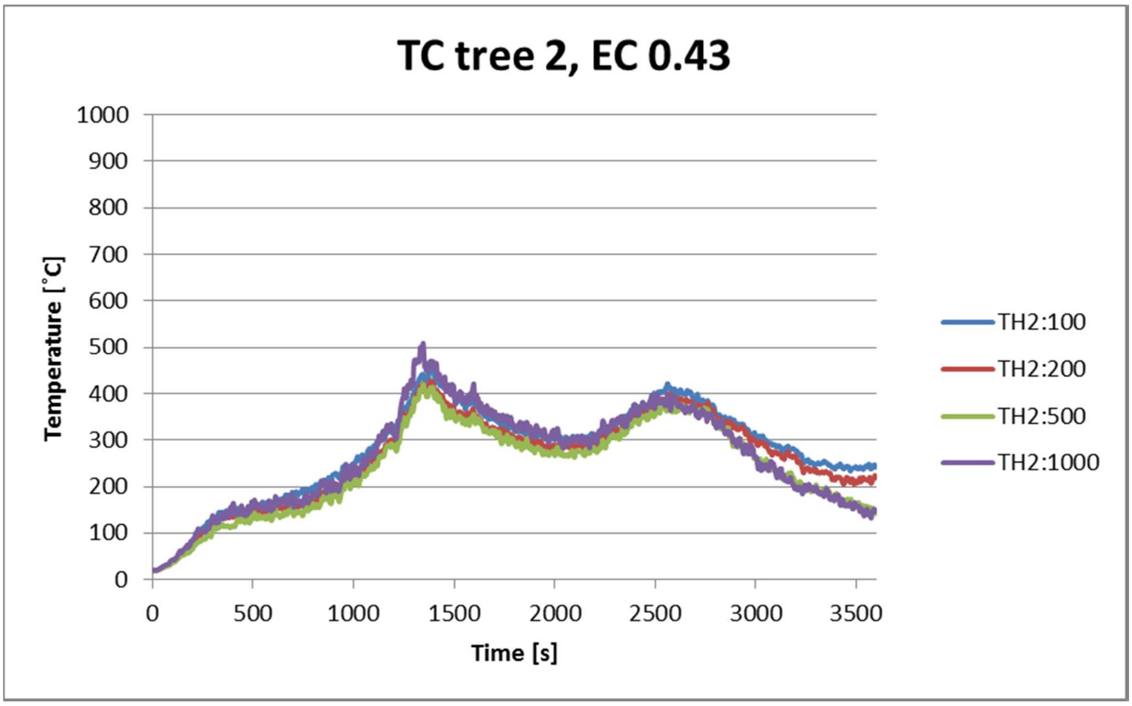


Figure 61. Temperatures in tree 2 in simulation 5.

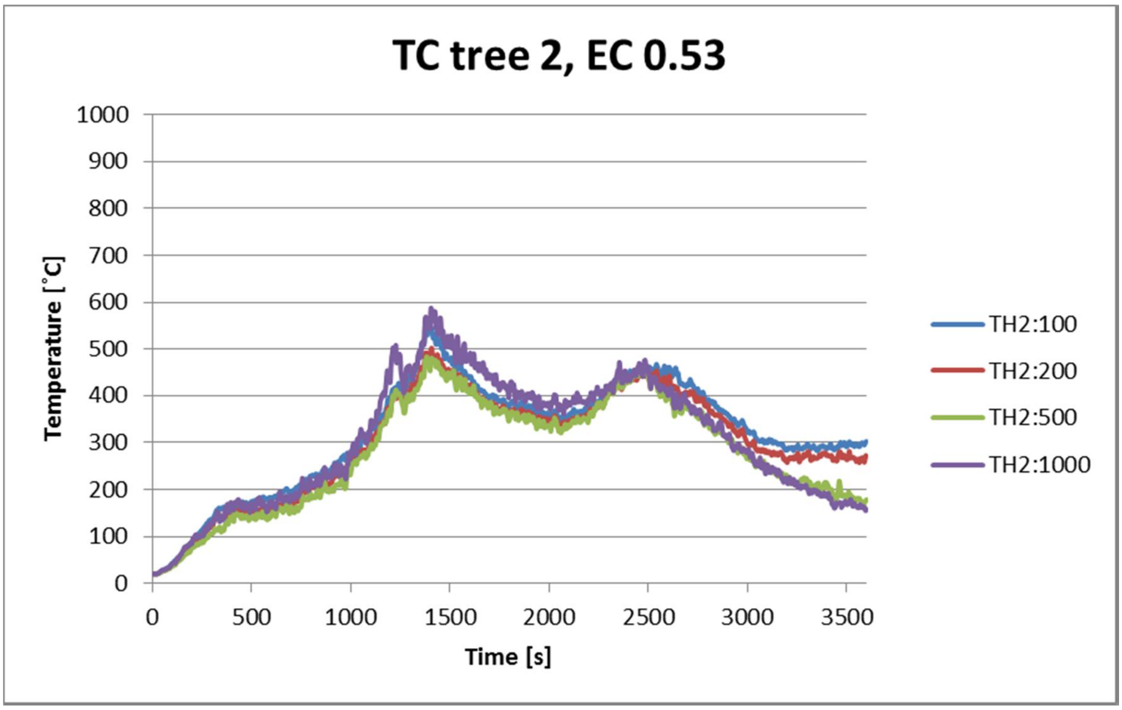


Figure 62. Temperatures in tree 2 in simulation 6.

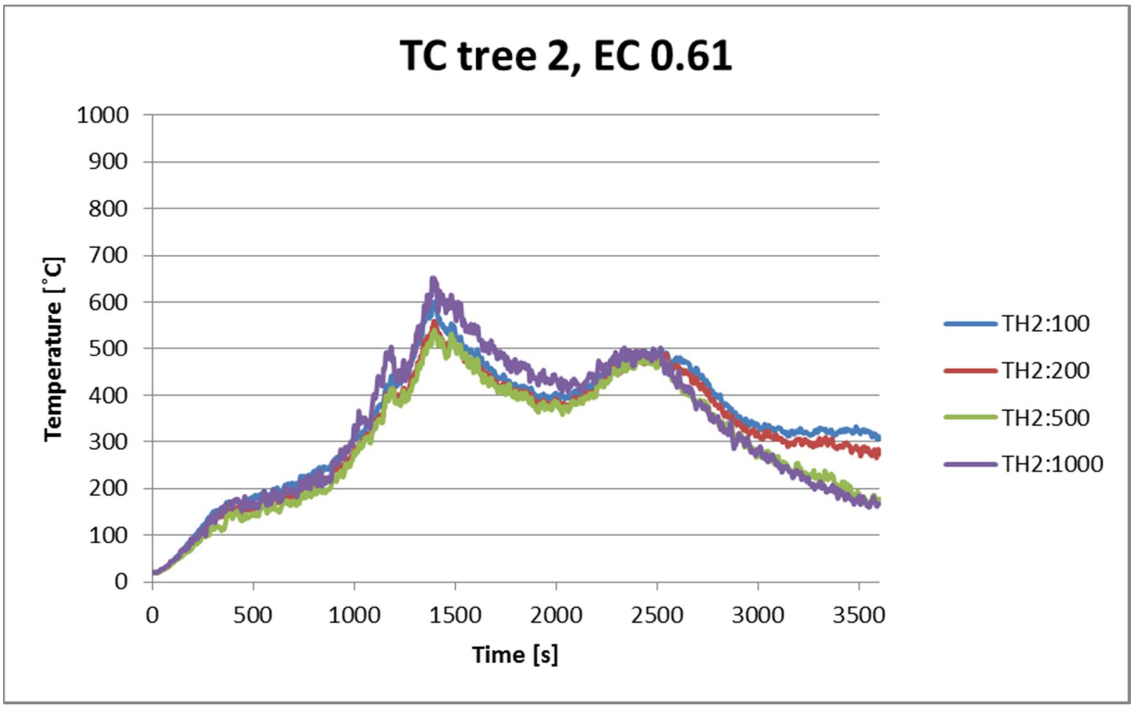


Figure 63. Temperatures in tree 2 in simulation 7.

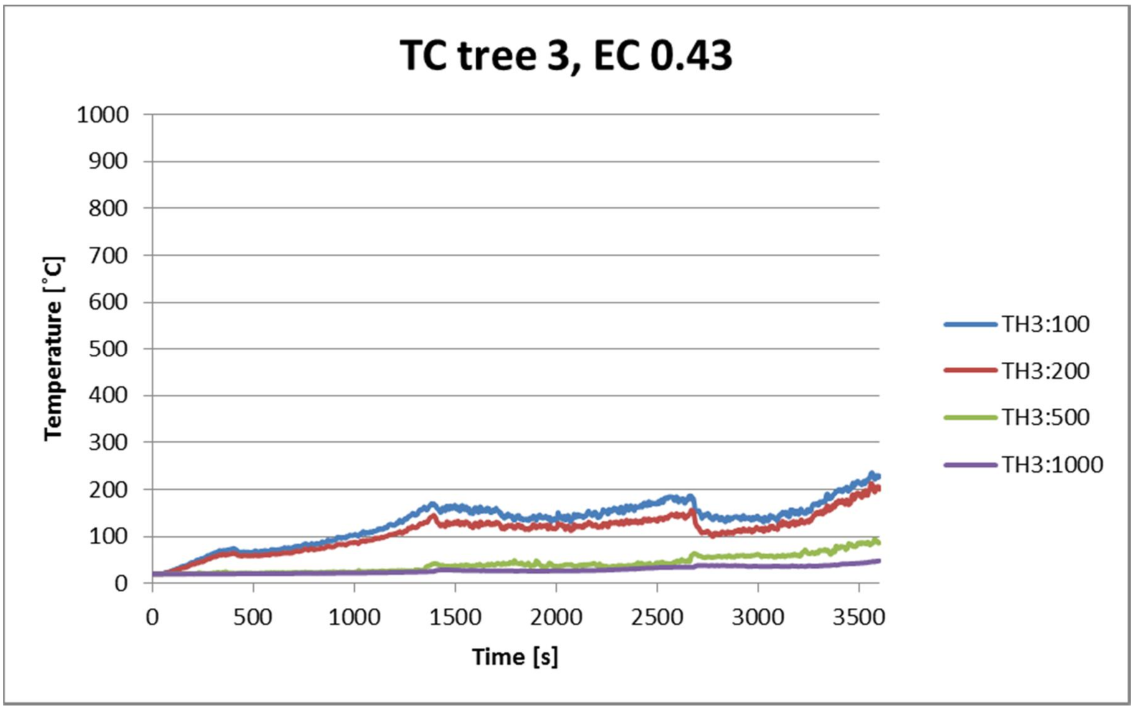


Figure 64. Temperatures in tree 3 in simulation 5.

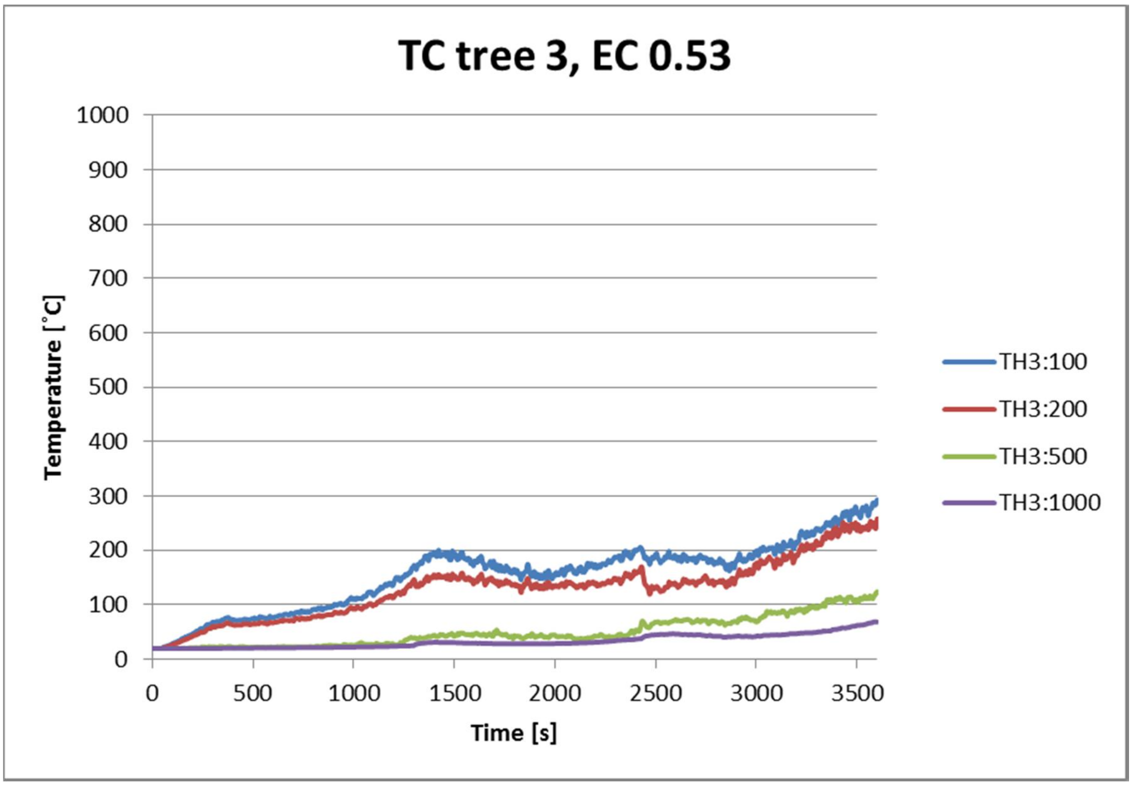


Figure 65. Temperatures in tree 3 in simulation 6.

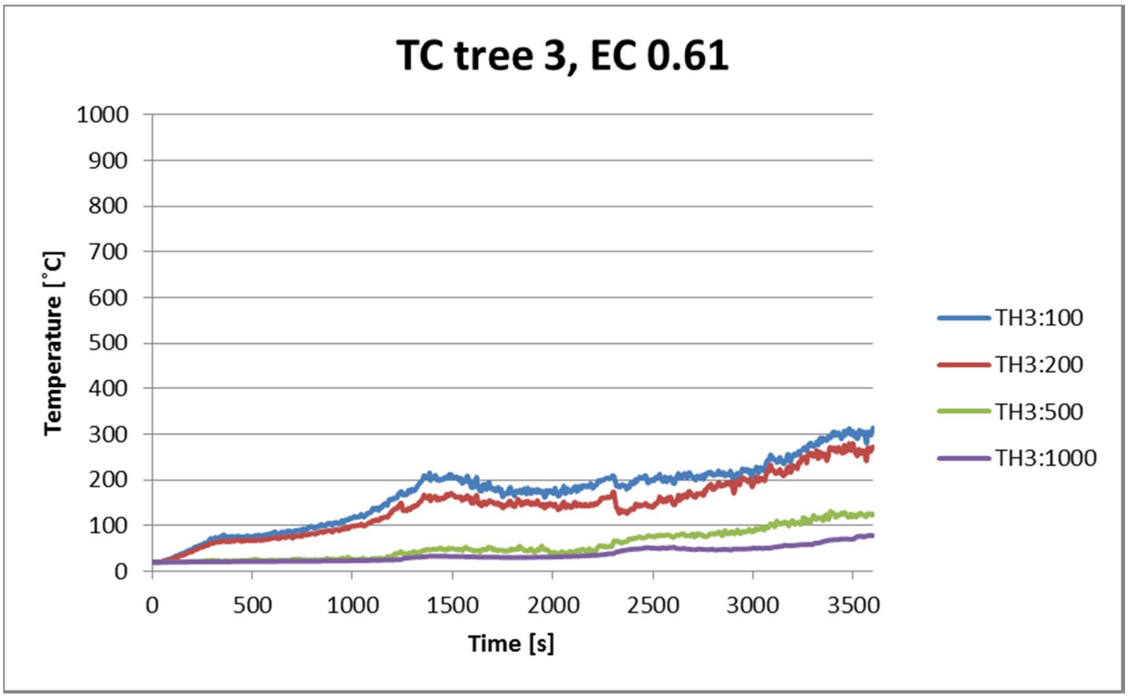


Figure 66. Temperatures in tree 3 in simulation 7.

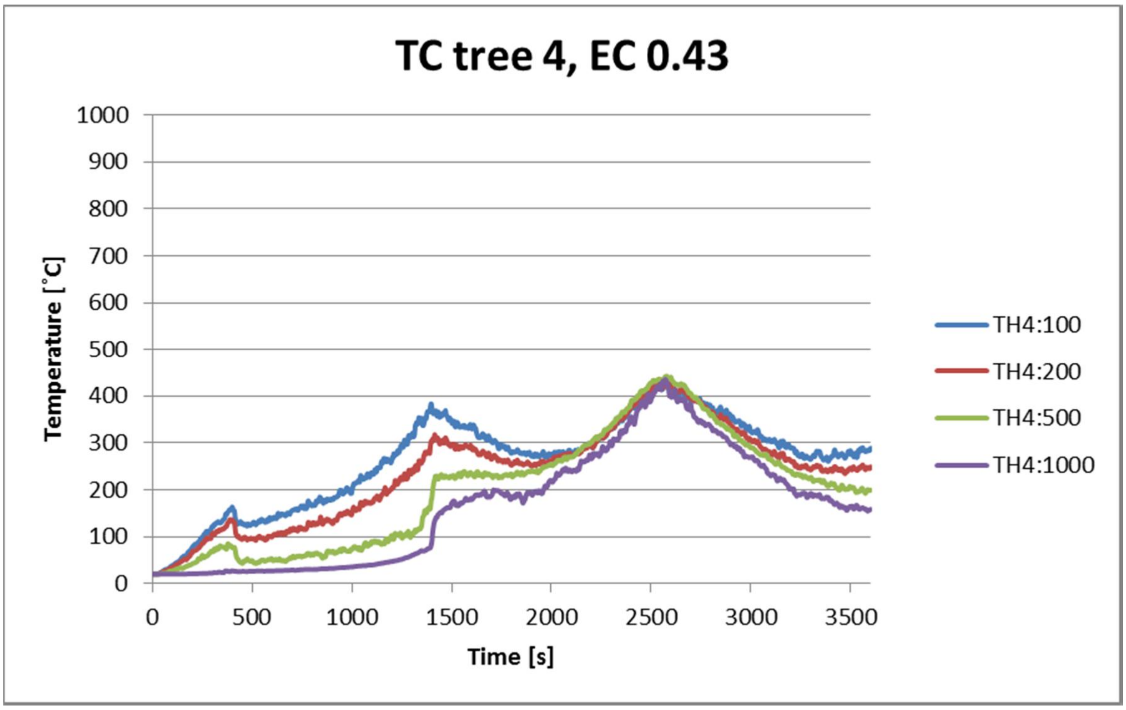


Figure 67. Temperatures in tree 4 in simulation 5.

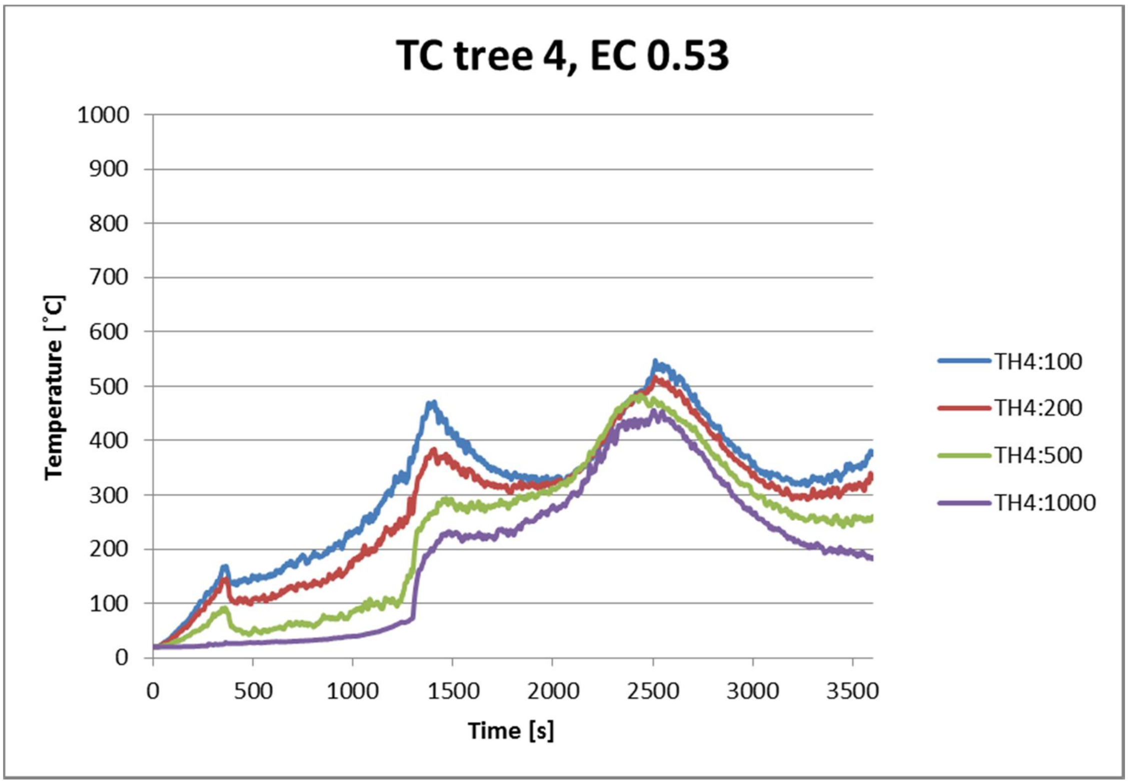


Figure 68. Temperatures in tree 4 in simulation 6.

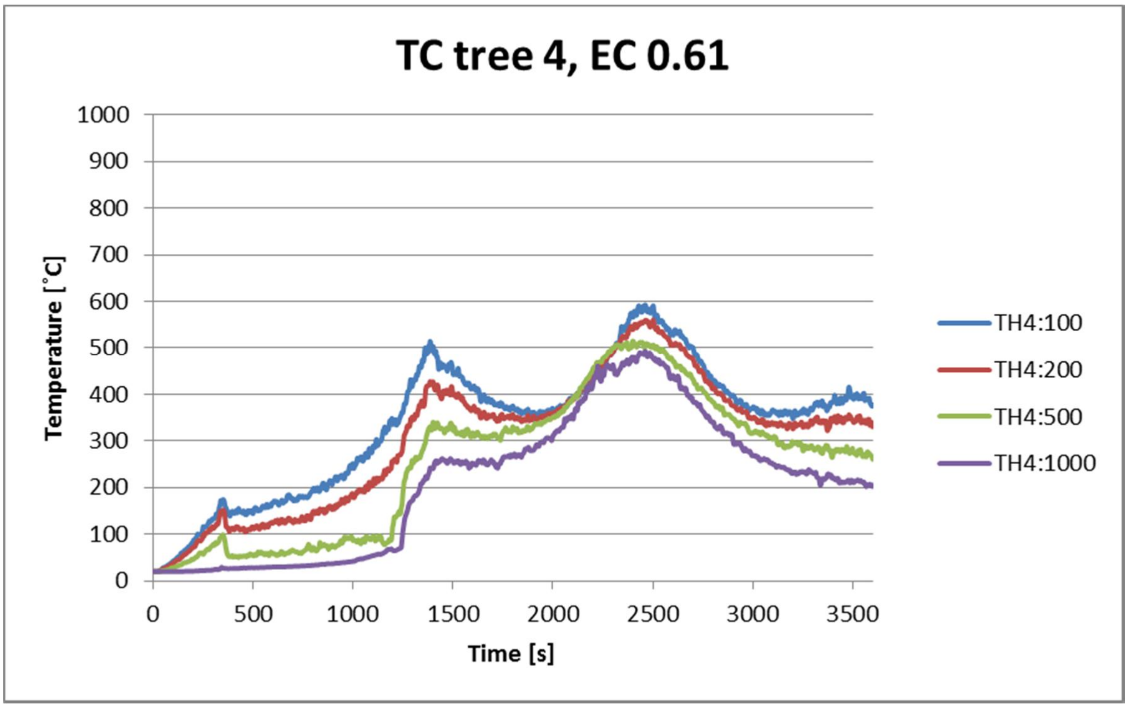


Figure 69. Temperatures in tree 4 in simulation 7.

For the comparisons HRR and temperatures in the simulations 1 and 4-7 are collected to Figs. 70-75.

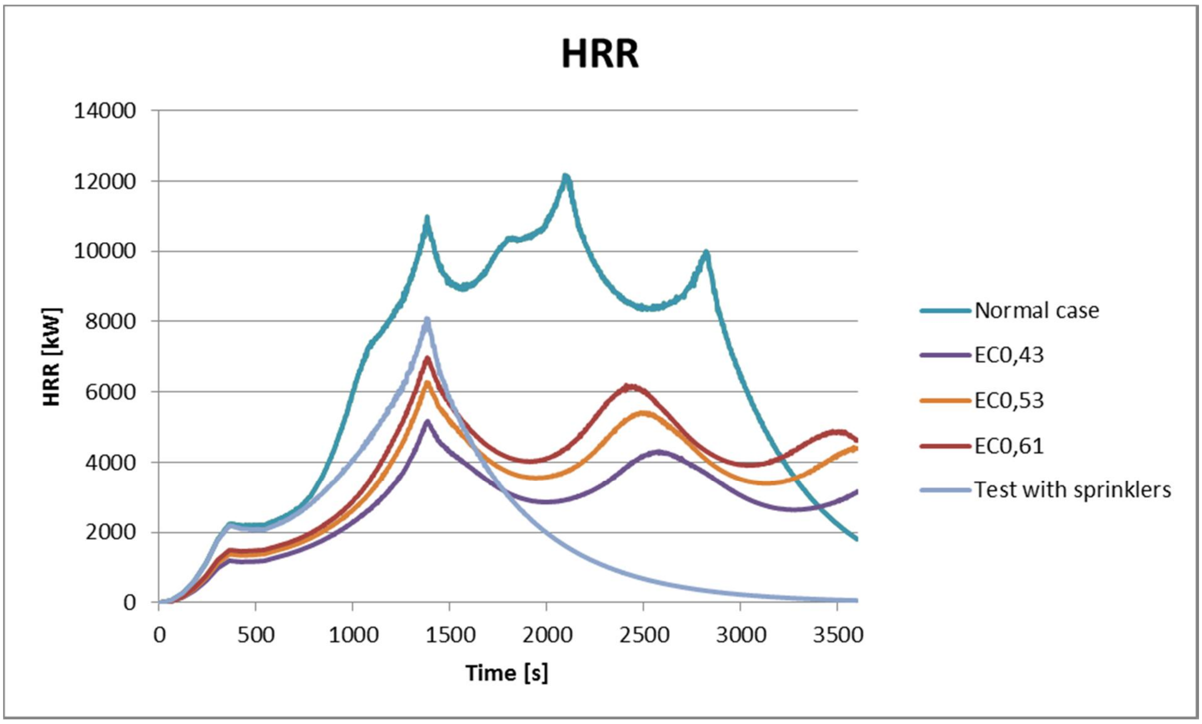


Figure 70. HRR curves in simulations.

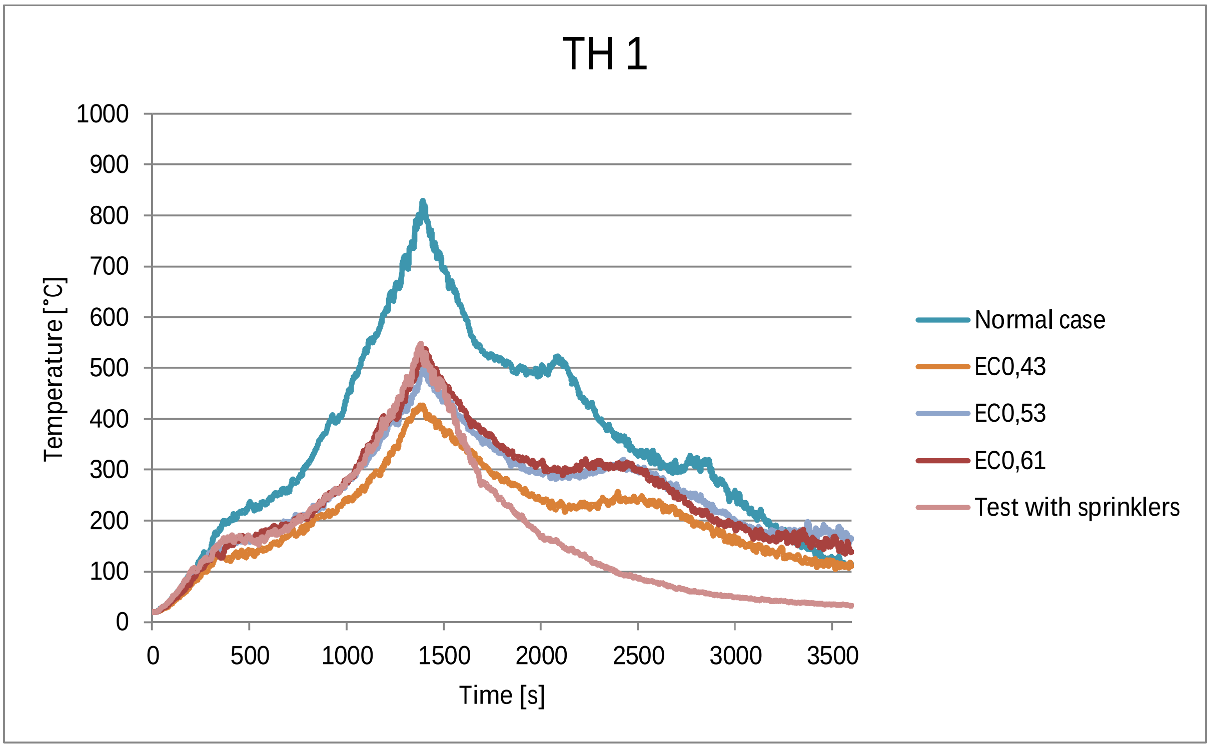


Figure 71. Temperatures in tree 1 at the level of 2,8m above floor in simulations.

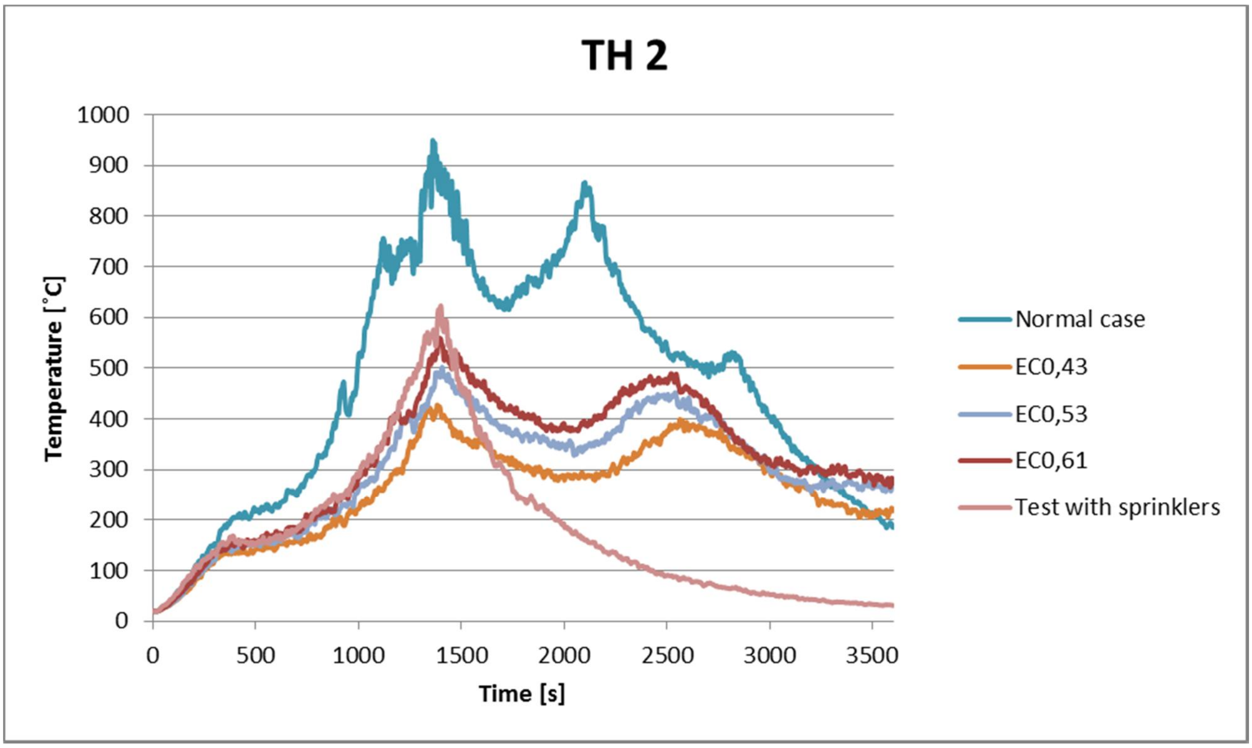


Figure 72. Temperatures in tree 2 at the level of 2,8m above floor in simulations.

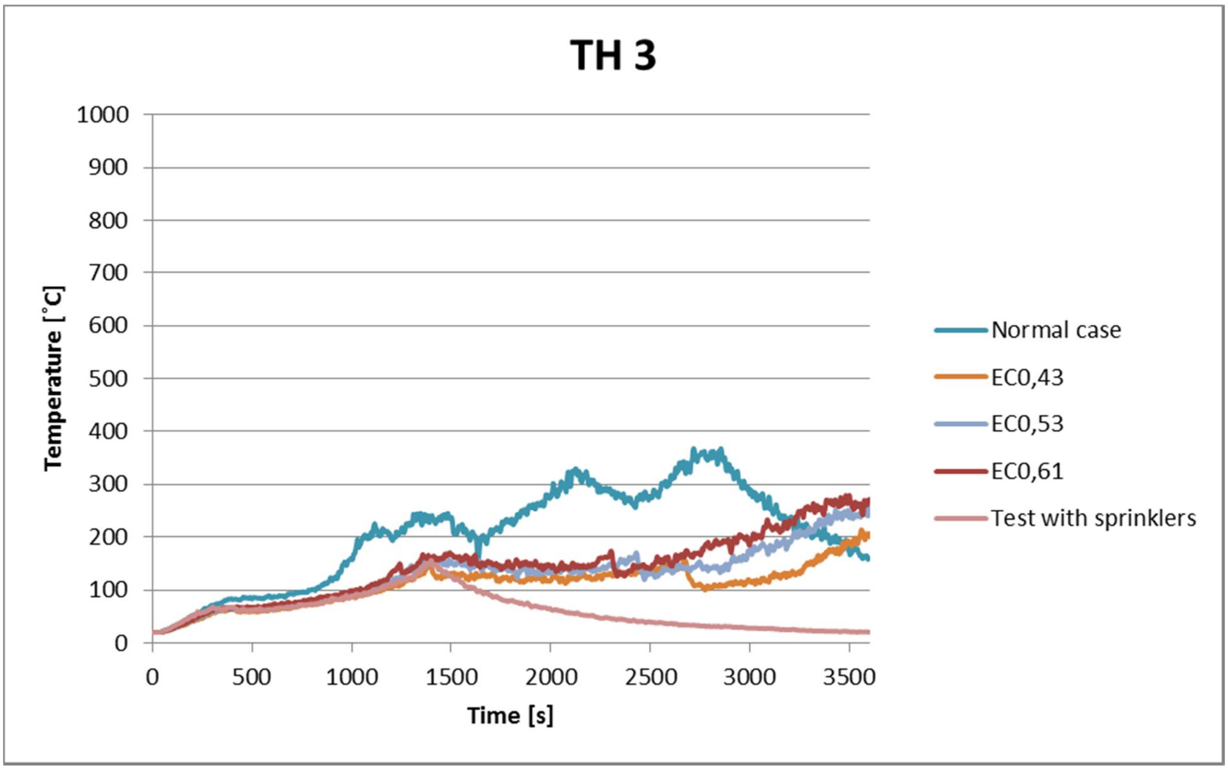


Figure 73. Temperatures in tree 3 at the level of 2,8m above floor in simulations.

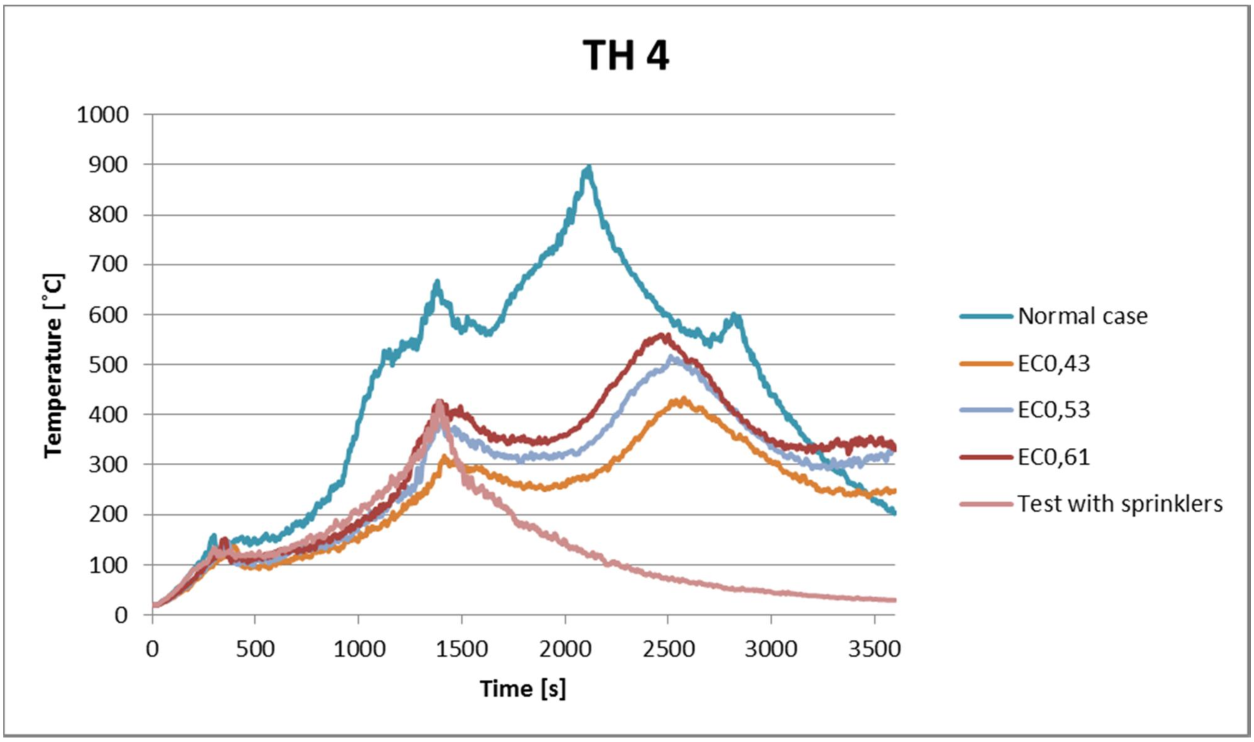
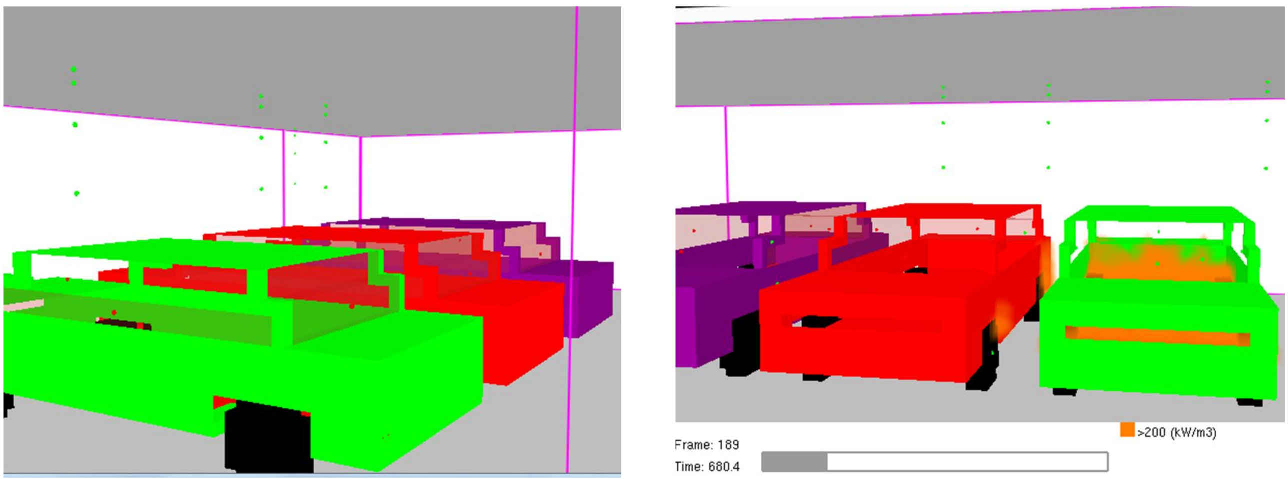
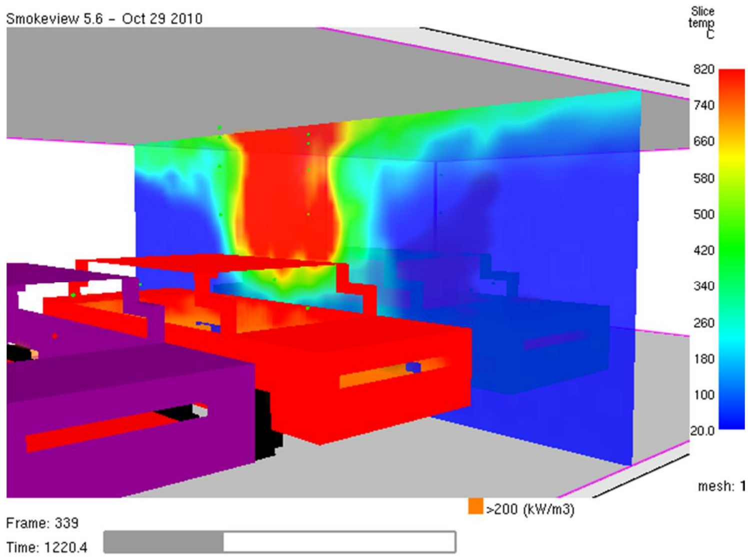


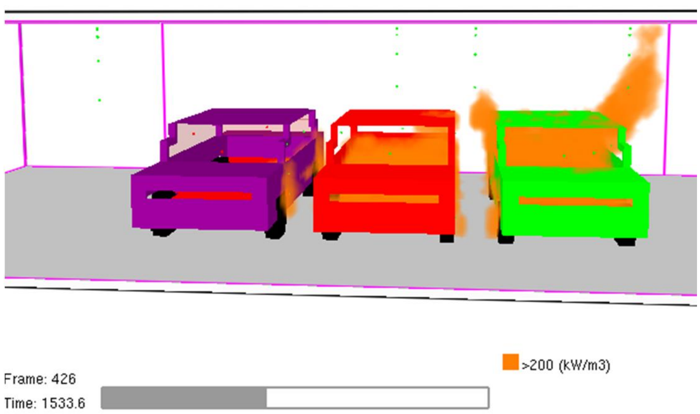
Figure 74. Temperatures in tree 4 at the level of 2,8m above floor in simulations.

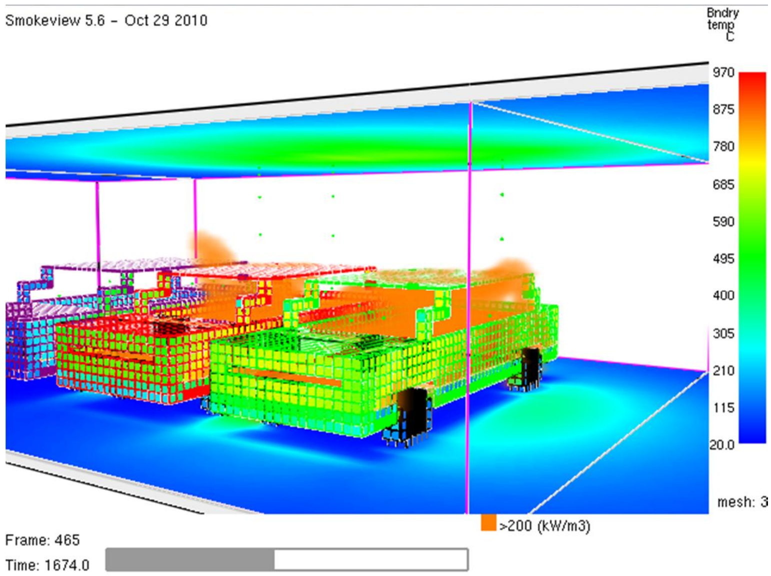
Based on these results the Eurocode reduction of fire load ("EC0,61" in figures) gives the same maximum temperatures as the simulation with sprinkler ("Test with sprinklers" in figures) at the first peak of HRR, about at 1500 s. The Eurocode reduction does not take into account the fact that adjacent cars do not ignite, as is the case in the simulation and in the BRE test.

Fig. 75 illustrates the development of the fire without sprinklers, the simulation 2.




Smokeview 5.6 - Oct 29 2010
Slice temp C
820
740
660
580
500
420
340
260
180
100
20.0
mesh: 1
>200 (kW/m3)
Frame: 339
Time: 1220.4


>200 (kW/m3)
Frame: 426
Time: 1533.6


Smokeview 5.6 - Oct 29 2010
Bndry temp C
970
875
780
685
590
495
400
305
210
115
20.0
mesh: 3
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Frame: 465
Time: 1674.0

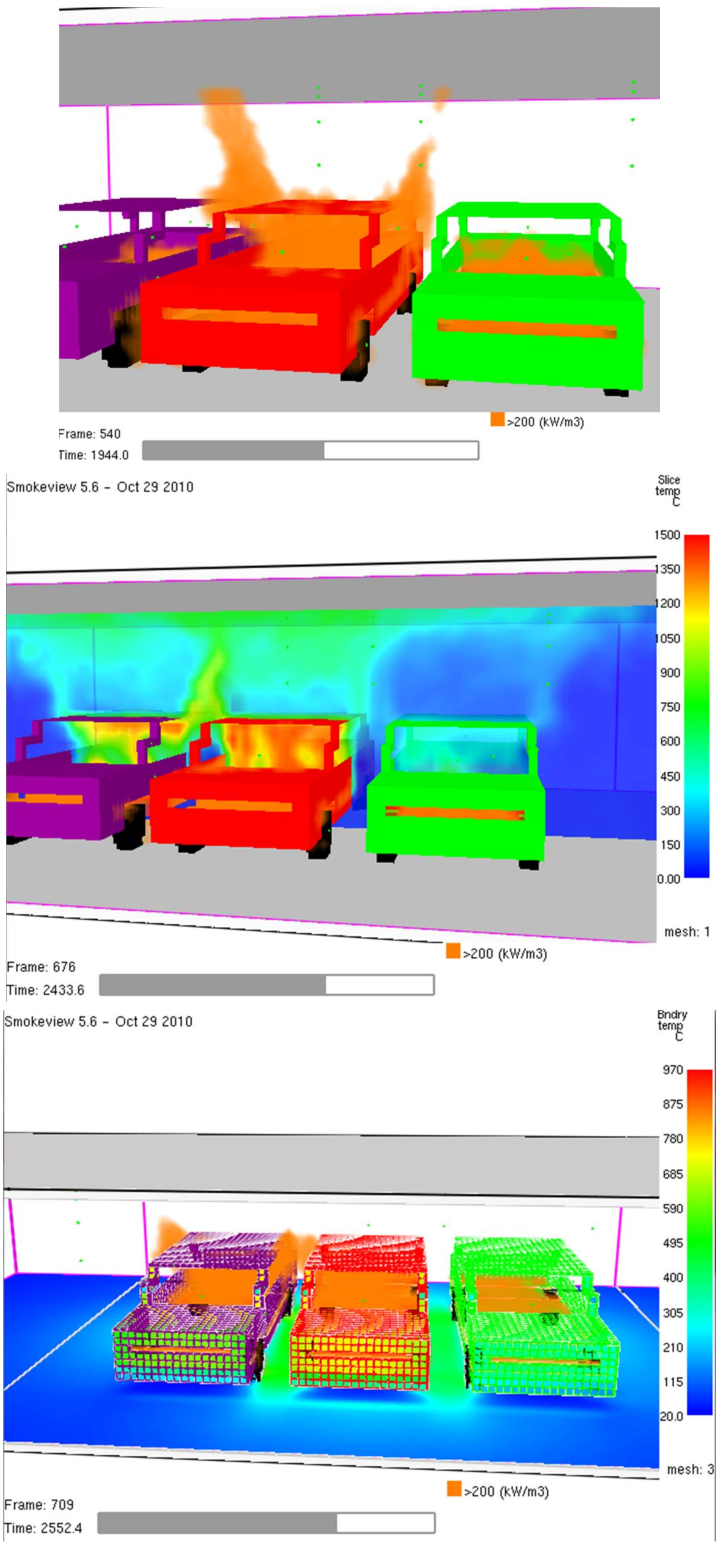

Figure 75. Fire development without sprinklers.

Figure 76. illustrates the development of the fire with sprinklers, the simulation 4.

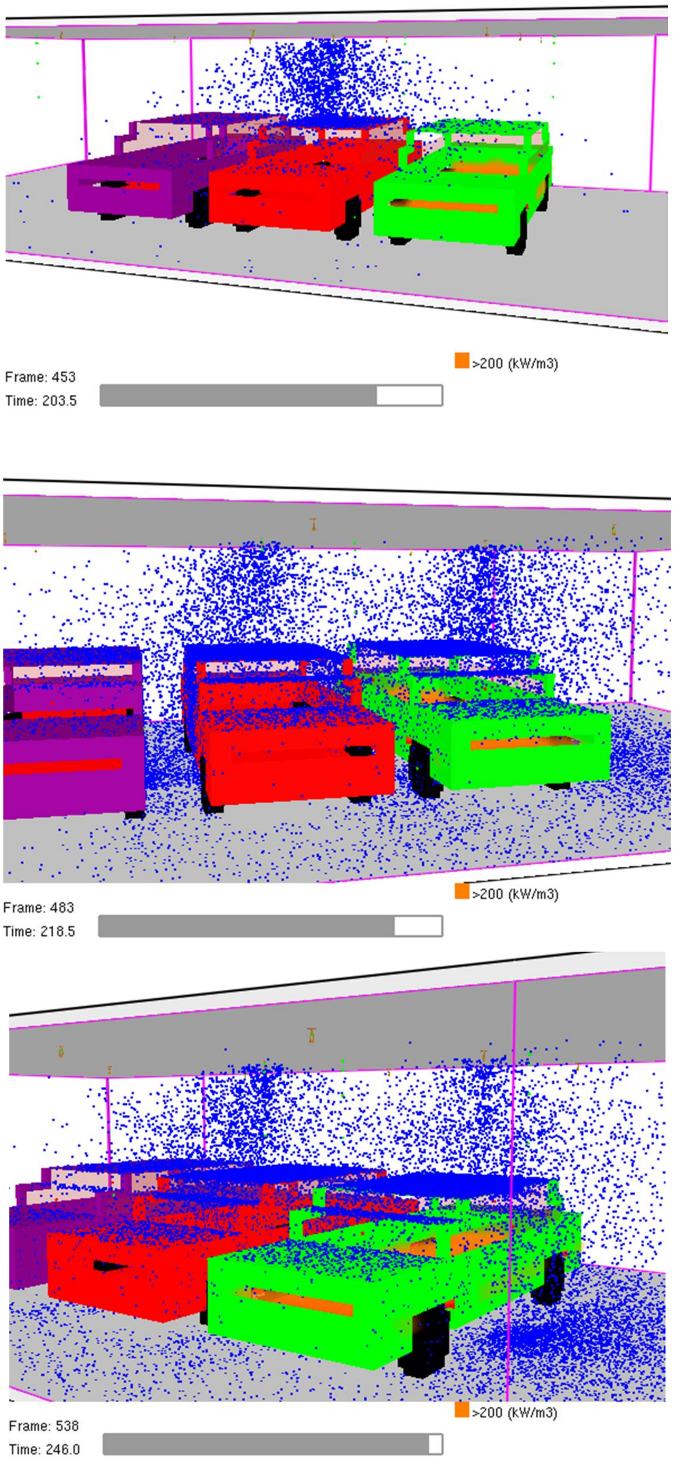

Figure 76. Fire development with sprinklers.

Conclusions

The first conclusion is that the proposed car fire model for FDS seemed to work well with and without sprinklers when the criteria were the gas temperatures got from the model and reference temperatures were those of full scale tests done in UK [BRE, 2009]. The second conclusion is that the Eurocode reduction of the fire load with sprinklers gives the same maximum temperatures as the simulation with sprinklers at the first peak of HRR. The Eurocode reduction does not take into account the fact that adjacent cars do not ignite, as is the case using the developed model and observed in the tests in the literature.

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Appendix A. FDS input file for Model 2, virtual car park simulation with Eurocode factor

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&TIME TWFIN=3600.0 /

------- LATTIA JA KATTO, EI SEINIÄ------------

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    THICKNESS              = 0.10 /

&MATL ID                   = 'CONCRETE'
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    DENSITY                = 2400. /

&OBST XB= 0.0, 8.0, 0.0, 16.0, 3.0, 3.1, SURF_ID='ROOF' / Katto
&OBST XB= 0.0, 8.0, 0.0, 16.0, -0.1, 0.0, SURF_ID='ROOF' / Lattia

---------- PALAVA OSA ---------------------------

&MATL ID                   = 'FABRIC'
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    CONDUCTIVITY           = 0.1
    SPECIFIC_HEAT          = 1.0
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&MATL ID                   = 'FOAM'
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    SPECIFIC_HEAT          = 1.0
    DENSITY                = 40. /

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    SPECIFIC_HEAT          = 1.9
    DENSITY                = 900. /

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-KEULA
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-TURVAKAARET
Vasen etu:
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&OBST XB=3.0,3.1,9.5,9.6,1.2,1.5, SURF_ID='CAR_BODY' , COLOR= 'PURPLE', PERMIT_HOLE=.FALSE.'/

Oikea etu:
&OBST XB=2.6,2.7,6.4,6.5,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=2.6,2.7,8.8,8.9,1.0,1.2, SURF_ID='CAR_BODY' , COLOR= 'RED', PERMIT_HOLE=.FALSE./
&OBST XB=2.6,2.7,11.2,11.3,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

&OBST XB=2.6,3.1,6.4,6.5,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=2.6,3.1,8.8,8.9,1.2,1.3, SURF_ID='CAR_BODY' , COLOR= 'RED', PERMIT_HOLE=.FALSE./
&OBST XB=2.6,3.1,11.2,11.3,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

&OBST XB=3.0,3.1,6.4,6.5,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=3.0,3.1,8.8,8.9,1.2,1.5, SURF_ID='CAR_BODY' , COLOR= 'RED', PERMIT_HOLE=.FALSE./
&OBST XB=3.0,3.1,11.2,11.3,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

Vasen taka:
&OBST XB=5.6,5.7,4.7,4.8,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=5.6,5.7,7.1,7.2,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'RED', PERMIT_HOLE=.FALSE. /
&OBST XB=5.6,5.7,9.5,9.6,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

&OBST XB=5.4,5.7,4.7,4.8,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.7,7.1,7.2,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'RED', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.7,9.5,9.6,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

&OBST XB=5.4,5.5,4.7,4.8,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.5,7.1,7.2,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'RED', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.5,9.5,9.6,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

Oikea taka:
&OBST XB=5.6,5.7,6.4,6.5,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=5.6,5.7,8.8,8.9,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'RED', PERMIT_HOLE=.FALSE. /
&OBST XB=5.6,5.7,11.2,11.3,1.0,1.2, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

&OBST XB=5.4,5.7,6.4,6.5,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.7,8.8,8.9,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'RED', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.7,11.2,11.3,1.2,1.3, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

```
&OBST XB=5.4,5.5,6.4,6.5,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'GREEN', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.5,8.8,8.9,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'RED', PERMIT_HOLE=.FALSE. /
&OBST XB=5.4,5.5,11.2,11.3,1.2,1.5, SURF_ID='CAR_BODY', COLOR= 'PURPLE', PERMIT_HOLE=.FALSE. /

-----------RIKKOUTUVAT IKKUNAT--------------------

&MATL ID                = 'LAMINOITU LASI',
    FYI                 = 'http://www.aisglass.com/pvb_laminated.asp',
    SPECIFIC_HEAT       =1.968,
    DENSITY             =2200.,
    CONDUCTIVITY        =0.2077,
    EMISSIVITY          =0.9/

&MATL ID                = 'TEMPERED GLASS',
    FYI                 = 'http://www.saint-gobain-sekurit.com/fr/?nav1=GC&fn=intro_glass_auto.html#a2',
    SPECIFIC_HEAT       =0.8,
    DENSITY             =2500.,
    CONDUCTIVITY        =0.8/

&SURF   ID              = 'TUULILASI',
        MATL_ID         ='LAMINOITU LASI',
        THICKNESS       =0.004/

&SURF   ID              = 'MUUT IKKUNAT',
        MATL_ID         ='TEMPERED GLASS',
         FYI            = 'Ikkunat rikkoutuvat lämpötilassa 250C (http://www.glazette.com/Glass-Knowledge-Bank-25/tempered-glass.html)'
        THICKNESS       =0.006/

---Auto 1 --
&OBST XB=2.7,5.6,4.7,4.705,1.0,1.2, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det1_1'/
&OBST XB=2.7,5.6,6.5,6.505,1.0,1.2, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det1_2'/

Takalasi
&OBST XB=5.695,5.7,4.8,6.4,1.0,1.3, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det1_3'/
&OBST XB=5.5,5.7,4.8,6.4,1.3,1.305, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det1_3'/
&OBST XB=5.5,5.505,4.8,6.4,1.3,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det1_3'/

Etulasi
&OBST XB=2.6,2.605,4.8,6.4,1.0,1.3, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det1_4'/
&OBST XB=2.6,3.0,4.8,6.4,1.3,1.305, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det1_4'/
&OBST XB=3.0,3.005,4.8,6.4,1.3,1.5, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det1_4'/

&DEVC XB=2.7,5.6,4.7,4.705,1.0,1.2, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det1_1', IOR=2,  INITIAL_STATE=.TRUE./
&DEVC XB=2.7,5.6,6.5,6.505,1.0,1.2, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det1_2', IOR=-2, INITIAL_STATE=.TRUE./
&DEVC XB=5.695,5.7,4.8,6.4,1.0,1.3, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det1_3', IOR=-1, INITIAL_STATE=.TRUE./
&DEVC XB=2.6,2.605,4.8,6.4,1.0,1.3, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det1_4', IOR=1, INITIAL_STATE=.TRUE./
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---Auto2--
&OBST XB=2.7,5.6,7.1,7.105,1.0,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det2_1'/
&HOLE XB=2.7,3.1,7.1,7.2,1.2,1.5 /
&HOLE XB=5.4,5.6,7.1,7.2,1.2,1.5 /

&OBST XB=2.7,5.6,8.895,8.9,1.0,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det2_2'/
&HOLE XB=2.7,3.1,8.8,8.9,1.2,1.5 /
&HOLE XB=5.4,5.6,8.8,8.9,1.2,1.5 /

Takalasi
&OBST XB=5.695,5.7,7.2,8.8,1.0,1.3, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det2_3'/
&OBST XB=5.5,5.7,7.2,8.8,1.3,1.305, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det2_3'/
&OBST XB=5.5,5.505,7.2,8.8,1.3,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
TRANSPARENCY=0.3,DEVC_ID='det2_3'/

Etulasi
&OBST XB=2.6,2.605,7.2,8.8,1.0,1.3, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det2_4'/
&OBST XB=2.6,3.0,7.2,8.8,1.3,1.305, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det2_4'/
&OBST XB=3.0,3.005,7.2,8.8,1.3,1.5, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det2_4'/

&DEVC XB=3.1,5.4,7.1,7.105,1.0,1.5, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det2_1', IOR=2, INITIAL_STATE=.TRUE./
&DEVC XB=3.1,5.4,8.895,8.9,1.0,1.5, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det2_2', IOR=-2, INITIAL_STATE=.TRUE./
&DEVC XB=5.695,5.7,7.2,8.8,1.0,1.3, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det2_3', IOR=-1, INITIAL_STATE=.TRUE./
&DEVC XB=2.6,2.605,7.2,8.8,1.0,1.3, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det2_4', IOR=1, INITIAL_STATE=.TRUE./

---Auto3---
&OBST XB=2.7,5.6,9.5,9.505,1.0,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN', TRANSPARENCY=0.3, DEVC_ID='det3_1'/
&HOLE XB=2.7,3.1,9.5,9.6,1.2,1.5 /
&HOLE XB=5.4,5.6,9.5,9.6,1.2,1.5 /

&OBST XB=2.7,5.6,11.295,11.3,1.0,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN', TRANSPARENCY=0.3, DEVC_ID='det3_2'/
&HOLE XB=2.7,3.1,11.2,11.3,1.2,1.5 /
&HOLE XB=5.4,5.6,11.2,11.3,1.2,1.5 /

Takalasi
&OBST XB=5.695,5.7,9.6,11.2,1.0,1.3, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
 TRANSPARENCY=0.3,DEVC_ID='det3_3'/
&OBST XB=5.5,5.7,9.6,11.2,1.3,1.305, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
 TRANSPARENCY=0.3,DEVC_ID='det3_3'/
&OBST XB=5.5,5.505,9.6,11.2,1.3,1.5, SURF_ID='MUUT IKKUNAT', COLOR='BROWN',
 TRANSPARENCY=0.3,DEVC_ID='det3_3'/

Etulasi
&OBST XB=2.6,2.605,9.6,11.2,1.0,1.3, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det3_4'/
&OBST XB=2.6,3.0,9.6,11.2,1.3,1.305, SURF_ID='TUULILASI', COLOR='INVISIBLE',
DEVC_ID='det3_4'/
&OBST XB=3.0,3.005,9.6,11.2,1.3,1.5, SURF_ID='TUULILASI', COLOR='INVISIBLE',
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DEVC_ID='det3_4'/

&DEVC XB=3.1,5.4,9.5,9.505,1.0,1.5, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det3_1', IOR=2, INITIAL_STATE=.TRUE./
&DEVC XB=3.1,5.4,11.295,11.3,1.0,1.4, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det3_2', IOR=-2, INITIAL_STATE=.TRUE./
&DEVC XB=5.695,5.7,9.6,11.2,1.0,1.3, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det3_3', IOR=-1, INITIAL_STATE=.TRUE./
&DEVC XB=2.6,2.605,9.6,11.2,1.0,1.3, QUANTITY='WALL_TEMPERATURE', STATISTICS='MAX',
SETPOINT=300., ID='det3_4', IOR=1, INITIAL_STATE=.TRUE./

------------- EI SEINIÄ ------------------------

&VENT XB=0.0,0.0,0.0,16.0,0.0,3.0, SURF_ID='OPEN' /
&VENT XB=8.0,8.0,0.0,16.0,0.0,3.0, SURF_ID='OPEN' /
&VENT XB=0.0,8.0,0.0,0.0,0.0,3.0, SURF_ID='OPEN' /
&VENT XB=0.0,8.0,16.0,16.0,0.0,3.0, SURF_ID='OPEN' /

------ TEMPERATURE TREE ---------------
&PROP   ID                  ='TypeK',
        BEAD_DIAMETER  =0.0015,
        BEAD_DENSITY     =8667.,
        BEAD_SPECIFIC_HEAT=0.46 / http://www.gilsoneng.com/reference/tcinfo.pdf

1.
&DEVC XYZ= 4.0, 4.5, 2.9, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH1:100' /
&DEVC XYZ= 4.0, 4.5, 2.8, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH1:200' /
&DEVC XYZ= 4.0, 4.5, 2.5, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH1:500' /
&DEVC XYZ= 4.0, 4.5, 2.0, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH1:1000' /

2.
&DEVC XYZ= 4.0, 6.8, 2.9, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH2:100' /
&DEVC XYZ= 4.0, 6.8, 2.8, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH2:200' /
&DEVC XYZ= 4.0, 6.8, 2.5, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH2:500' /
&DEVC XYZ= 4.0, 6.8, 2.0, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH2:1000' /

3.
&DEVC XYZ= 1.2, 11.6 2.9, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH3:100' /
&DEVC XYZ= 1.2, 11.6, 2.8, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH3:200' /
&DEVC XYZ= 1.2, 11.6, 2.5, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH3:500' /
&DEVC XYZ= 1.2, 11.6, 2.0, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH3:1000' /

4.
&DEVC XYZ= 4.0, 8.0 2.9, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH4:100' /
&DEVC XYZ= 4.0, 8.0, 2.8, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH4:200' /
&DEVC XYZ= 4.0, 8.0, 2.5, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH4:500' /
&DEVC XYZ= 4.0, 8.0, 2.0, PROP_ID='TypeK', QUANTITY='THERMOCOUPLE', ID='TH4:1000' /

&DEVC XYZ= 3.9, 8.0, 0.5, QUANTITY='WALL_TEMPERATURE', ID='PINTALAMPO2', IOR=3 /
&DEVC XYZ= 3.9, 10.4, 0.5, QUANTITY='WALL_TEMPERATURE', ID='PINTALAMPO3', IOR=3 /

&DEVC XYZ= 2.4, 6.5, 0.3, QUANTITY='WALL_TEMPERATURE', ID='RENGASLÄMPÖ1', IOR=2 /
&DEVC XYZ= 2.4, 7.1, 0.3, QUANTITY='WALL_TEMPERATURE', ID='RENGASLÄMPÖ2', IOR=-2 /

&DEVC XYZ= 2.9, 9.5, 0.5, QUANTITY='NET HEAT FLUX', ID='NHF1', IOR=-2 /
&DEVC XYZ= 2.9, 9.5, 0.8, QUANTITY='NET HEAT FLUX', ID='NHF2', IOR=-2 /
&DEVC XYZ= 2.8, 9.5, 1.25, QUANTITY='NET HEAT FLUX', ID='NHF3', IOR=-2 /

&DEVC XYZ= 2.6,5.2,1.2, QUANTITY='NET HEAT FLUX', ID='NHFW1', IOR=1 /
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